



FINAL GROUNDWATER SOURCE CONTROL EXTRACTION SYSTEM TEST PLAN NW NATURAL GASCO SITE

Prepared for

NW Natural

Prepared by

Anchor QEA, LLC

6650 Southwest Redwood Lane, Suite 333

Portland, Oregon 97224

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Anchor QEA, LLC

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LIST OF ACRONYMS AND ABBREVIATIONS

ΔH	delta-H
\pm	plus or minus
Anchor QEA	Anchor QEA, LLC
CDR	<i>Revised Groundwater Source Control Construction Design Report</i>
COI	constituent of interest
DEQ	Oregon Department of Environmental Quality
DNAPL	dense nonaqueous phase liquid
FAMM	Fuel and Marine Marketing
FDR	<i>Draft Groundwater Source Control Final Design Report</i>
gpm	gallon per minute
HC&C	hydraulic control and containment
NPDES	National Pollutant Discharge Elimination System
ORP	oxidation reduction potential
PAH	polycyclic aromatic hydrocarbon
Plan	Groundwater Source Control Extraction System Test Plan
PLC	programmable logic control
R^2	squared errors and model-data correlation
RAO	Remedial Action Objective
SAP	Sampling and Analysis Plan
set-point	ΔH setting at a control well
Siltronic	Siltronic Corporation
SIM	Selective Ion Monitoring
Site	Gasco site
TarGOST	Tar-Specific Green Optical Screening Tool
WAD	weak acid dissociable
WBZ	water bearing zone
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

1 INTRODUCTION

1.1 Background

The groundwater hydraulic control and containment (HC&C) system has been constructed on the NW Natural and Siltronic Corporation (Siltronic) owned portions of the Gasco site (Site). This source control work is being completed consistent with the requirements of: 1) the Joint Order (DEQ Order No. ECVC-NWR-00-27 to NW Natural and Siltronic, dated October 4, 2000); and 2) the Voluntary Agreement (DEQ No. WMCVM-NWR-94-13, dated August 8, 1994, as amended July 19, 2006). On March 21, 2008, DEQ selected source control actions to address potential impacts to the Willamette River from manufactured gas plant and solvent contamination at the Gasco and Siltronic properties.

The two major components of the HC&C system are the groundwater extraction system and the treatment system. Locations of extraction wells, monitoring wells, and piezometers are shown on the General Well Location Map (see Figure 1) and in more detail on the Map of Groundwater Extraction and Treatment System (see Figures 2a through 2c). Locations and depths of extraction wells, monitoring wells, and piezometers are shown on the Geologic Cross Section A-A' (see Figures 3a through 3c).

The treated groundwater will be discharged to the Willamette River under a National Pollutant Discharge Elimination System (NPDES) permit. In April 23 and May 15, 2013 emails, the Oregon Department of Environmental Quality (DEQ) requested the preparation of this work plan for post-construction testing of the HC&C extraction system. Information from conducting this Groundwater Source Control Extraction System Test Plan (Plan) will be used to develop parameters and guidelines for long-term operation of the system.

Section 3.2.3 of the *Revised Groundwater Source Control Construction Design Report* (CDR; Anchor QEA 2012) provides the current design of the extraction system test plan. This Plan proposes revisions to the test plan in the CDR. This Plan was first submitted to DEQ on August 1, 2013. An August 12 email from DEQ indicated that the Plan was incomplete based on the agencies' preliminary review. In the August 12 comments, DEQ requested additional details on data needs, data collection objectives, and how and when data collection objectives would be met.

A workshop with DEQ and U.S. Environmental Protection Agency (USEPA) representatives was subsequently held on August 15 to discuss agency comments and revisions to the Plan. A revised version of this Plan was submitted to DEQ on September 9, 2013. DEQ provided general and specific comments on the September 9 version of this Plan in an October 1, 2013 email. An October 7 conference call was held with DEQ to discuss the October 1 comments. On October 11, a matrix was emailed to DEQ describing how DEQ's October 1 general and specific comments were going to be addressed in this final Plan.

DEQ's October 1 general and specific comments are addressed in this Plan. In the October 1 comments, DEQ requested that their general comments be incorporated into Sections 3 and 4 of the Plan. DEQ's general comments have been incorporated in to the Plan in the locations appropriate to the content of the comments, as listed below:

- DEQ's recommended list of data needs has been incorporated into Section 2.1 to set the stage for discussing data gathering objectives.
- DEQ's general criteria for collecting data have been incorporated into Section 3.1.
- DEQ's list of data gathering objectives has been incorporated into Section 2.2 because that section of the report covers the data objectives of the Plan. The application of the data objectives for the Phase 1 tests has been incorporated into Section 3.1.
- The use of hydraulic efficiency in the groundwater capture analysis has been incorporated into Section 5.1.1.
- The primary data gathering objectives for Phase 2 testing have been incorporated into Section 3.2.
- DEQ's requested dense nonaqueous phase liquid (DNAPL) removal wells are discussed in Section 5.3.
- DEQ's general comments are also addressed as needed in Section 4.

This final draft of the Plan is intended to fully address agency comments, facilitate DEQ approval, and enable initiation of the Plan as soon as possible.

1.2 Source Control Remedial Action Objectives

This section provides background information on source control system Remedial Action Objectives (RAOs). This Plan is designed to obtain data needed to develop system operational parameters to maintain hydraulic containment. On page 7, paragraph 1, of DEQ's

September 22, 2011 letter (Bayuk 2011), DEQ states that the RAOs for groundwater source control are as follows:

1. *prevent migration of contaminated groundwater from the uplands to the Willamette River along shoreline Segments 1 and 2, in a manner that;*
2. *minimizes DNAPL mobilization resulting from groundwater SCMs along the portion of Segment 1 where DNAPL occurs.*

Section 2 describes data gathering objectives to support operation of the extraction system for satisfactory attainment of the RAOs. Protocols for operating the extraction system to achieve full hydraulic containment while simultaneously controlling gradients to reduce the potential for DNAPL migration will be provided in the forthcoming Operations and Performance Monitoring Design Report.

This Plan is designed, in part, to gather data to assess how DNAPL is reacting to operation of the extraction system. The term “DNAPL exacerbation” has been used by DEQ in many of the documents associated with source control design, but to date the term has not been defined in a way that can be used for designing a monitoring program. DEQ has expressed in past documents that the source control system should be operated to achieve hydraulic containment of groundwater in the alluvium while simultaneously minimizing the exacerbation of DNAPL. NW Natural and DEQ anticipate that DNAPL in the immediate vicinity of an extraction well will potentially migrate to the extraction well and subsequently be removed, per the current design; therefore, this type of migration should not be considered exacerbation. It is anticipated that extraction of DNAPL will be a secondary benefit of system operation. DNAPL migration and monitoring plans are further discussed in Sections 2.2 and 4.2.

2 DATA GATHERING OBJECTIVES

2.1 Data Needs

An initial list of data needs were described by DEQ in the October 1 comments. NW Natural accepted the list as being complete and informed DEQ of this determination during the October 7 conference call. Data need number 2 was modified during the October 7 conference call and it was agreed that the following data needs would be incorporated into the Plan:

1. *Evaluate the design objectives of the upper Alluvium WBZ extraction wells located in the portion of shoreline Segment 1 where DNAPL occurs;*
2. *Compare average set-point settings (i.e., “set-points”) for each control well with the Willamette River staff gage at the end of each set-point test;*
3. *Assess the hydraulic influence of the HC&C system on control wells, monitoring wells, observations wells, and piezometers (performance monitoring installations) throughout the performance monitoring network;*
4. *Determine the relative hydraulic efficiency of performance monitoring installations throughout the performance monitoring network during HC&C system testing;*
5. *Allow data collection and evaluation methods to be refined at performance monitoring installations as appropriate;*
6. *Assess DNAPL occurrence, accumulation, and removal rates before HC&C system testing (i.e., baseline conditions) with measurements made during testing;*
7. *Inform NW Natural of adjustments that need to be made to the HC&C system during the test(s) to ensure adequate operational information is collected to support each phase of the test and full-scale full-time operation; and,*
8. *Collect data to assess the operation and hydraulic influence of the HC&C system under seasonally changing groundwater and river stage conditions.*

The data gathering objectives and the rest of this Plan will fulfill these data needs.

2.2 Assess System Operational Parameters

The primary operational parameter for the extraction system will be the delta-H (ΔH) setting at each control well. For this project, ΔH is defined as the difference between the elevation of the river level and the groundwater elevation at any monitoring well, piezometer, or extraction well. At wells where there is a negative ΔH , the river elevation is higher than the groundwater elevation at that location, and therefore, groundwater cannot be migrating to the river. At wells where there is a positive ΔH , the groundwater elevation is higher than the river elevation and

flow to the river is indicated. In this Plan, the ΔH setting at the control wells is termed the set-point.

A list of seven data collection objectives for each set-point test were described by DEQ in the October 1 comments and discussed in the October 7 conference call. During the October 7 conference call NW Natural accepted the seven data collection objectives described by DEQ as being complete and incorporated the list into this Plan.

The data collection objectives will evaluate the hydraulic influence of the HC&C system on performance monitoring installations during each set-point test by using hydrographs to:

1. Confirm the design objectives of the Upper Alluvium WBZ extraction wells in shoreline Segment 1 are maintained during each set-point test. Based on the information in the CDR, the hydraulic gradient design objectives include inducing horizontal gradients from the river toward the extraction wells, reducing the horizontal hydraulic gradients in the vicinity of each well by reducing the well spacing, and establishing upward vertical gradients from the Lower Alluvium to the Upper Alluvium. Note that this data collection objective description was modified from the description provided by DEQ in the October 1 comments based on agreements with NW Natural during the October 7 conference call.
2. Confirm that the water level elevations in the control wells are continuously lower than the river by approximately the set-point value.
3. Confirm that groundwater elevations in performance monitoring installations exhibiting “high” hydraulic efficiency are continuously more than 0.05-feet lower than the river stage.
4. Confirm that groundwater elevations in performance monitoring installations exhibiting “low” hydraulic efficiency are continuously more than 0.05-feet lower than the river stage or consistently more than 0.05-feet lower than the river stage based on analysis of water levels using the Serfes method.
5. Confirm that the groundwater elevations in performance monitoring installations constructed below the deep aquitard clearly show the groundwater gradient is from these installations toward extraction wells.
6. Confirm that groundwater elevations in performance monitoring installations located near the margins of the HC&C system (e.g., northern and southern ends, nearshore and offshore piezometers) are continuously more than 0.05-feet lower than the river stage or

are consistently more than 0.05-feet lower than the river stage based on analysis of water levels using the Serfes method.

7. Measure and monitor DNAPL removal rates throughout the entire initial HC&C system testing phase to assess the relationship between control well set-points and DNAPL accumulation rates.

The application of these objectives in conducting the tests is described in Section 3, and their use in analyzing the test data is described in Section 5.1. The preliminary hydraulic efficiencies of the performance monitoring wells are shown in Table 3 and are further discussed in Sections 3 and 4.

For operation of the system, a negative ΔH will be programmed at each control well and designated as the set-point. The programmable logic control (PLC) system will use water elevation data from control wells and the river to calculate ΔH in real time during operation of the system. The goal to meet the hydraulic containment RAO is to have negative ΔH between the river and the upland alluvial groundwater, indicating that groundwater is not discharging to the river. The PLC will instruct extraction wells to increase or decrease the pumping rate to maintain the set-point at the control well. Per the design, control wells are located approximately half way between extraction wells and are screened at approximately the same elevation in the alluvium as the extraction well that they control. Therefore, control wells should provide a representative groundwater elevation for that portion of the aquifer.

The overall data gathering objective is to determine if there is a negative ΔH being achieved by the extraction system down to the deep aquitard along the line of extraction wells. This effort will be conducted to satisfy data collection objective Nos. 1 through 6 previously described. This will be an effective method for verifying system performance without the need to install even more monitoring wells. The alluvium contains laterally discontinuous silt layers that could affect the groundwater flow regime between extraction wells and control wells. Groundwater elevation data obtained from nearby monitoring wells and piezometers during these tests will be evaluated to determine if the control well ΔH needs to be adjusted to better reflect hydraulic conditions throughout the alluvium.

As described subsequently in this Plan, the demonstration of hydraulic containment at wells screened below the deep aquitard will require the detailed mapping and evaluation of groundwater elevation data, supported by use of the groundwater flow model. A description

of the method to be used to demonstrate hydraulic containment below the aquitard will be provided to DEQ at the same time as the first data deliverable following initiation of the Phase 1 short-term tests.

Key parameters directly affected by ΔH are the extraction well pumping rates and groundwater elevation gradients that are induced in the alluvium during pumping. These two parameters will change to reflect changes in the ΔH setting at the control well. In general there should be a direct correlation between the magnitude of ΔH and the magnitude of the extraction well pumping rate and groundwater elevation gradient. Groundwater elevation gradients are measured between wells, whereas ΔH is measured between the river and each well.

One of the groundwater gradient data objectives is to document changing gradients for possible correlation with DNAPL monitoring data. This effort is expected to support data collection objective No. 7. Groundwater elevation gradients between wells will be measured primarily because increased gradients are a potential factor for DNAPL migration.

An increase in the magnitude of ΔH at a control well will generally result in an increased pumping rate at the extraction well and an increased groundwater elevation gradient. There will likely be exceptions to this general rule in cases where an increase in ΔH at one control well and resulting increased pumping rate, results in a decrease in the pumping rate at an adjacent extraction well due to overlapping zones of drawdown influence between extraction wells. The PLC automatically measures and records changes in discharge rates at extraction wells.

2.3 Assess Effects of Pumping on DNAPL

Section 3.2.2.5 of the CDR contains a detailed DNAPL monitoring program. The DNAPL monitoring program in the CDR consists of the following three main elements:

- Using Tar-Specific Green Optical Screening Tool (TarGOST) sampling methods
- Monitoring and recovery of DNAPL entering wells
- Monitoring of DNAPL entering the treatment system oil-water separators

The DNAPL monitoring program in this Plan is modeled after the one in the CDR and is intended to gather data needed to determine if potentially problematic DNAPL migration is occurring as a result of operating the HC&C system. For the purpose of this Plan, the potential

for problematic DNAPL migration would be indicated by the following DNAPL monitoring results:

- The new appearance of measurable DNAPL in the sump of a monitoring well or piezometer located between extraction wells and the river
- The new appearance of DNAPL in one of the TarGOST monitoring areas
- DNAPL appearance in TarGOST borings at depth intervals not previously observed near extraction wells

As described in Section 4.2.3, the feasibility of accurately measuring the volume and rate of DNAPL accumulation in the oil-water separators will be determined during system startup and testing. At this time it is uncertain if this approach will be a viable line of evidence for evaluating DNAPL movement.

The DNAPL monitoring program is described in Section 4.2. The plan for evaluation of the data to assess for potentially problematic DNAPL migration is described in Section 5.3.3.

2.4 Assess Need for Contingency Measures

Another data gathering objective is to assess the need for contingency measures. Successfully achieving both RAOs of hydraulic containment and minimization of potentially problematic DNAPL migration may require the implementation of contingency measures. The six types of contingency measures being considered are as follows:

1. Adjusting pumping parameters
2. Adjusting the depth of the pump intake in an extraction well
3. Changing monitoring wells that are being used as control wells
4. Adjusting the performance monitoring sampling and analytical program
5. Installing DNAPL extraction wells
6. Adding groundwater extraction wells

Contingency measure Nos. 1 through 5 could be triggered during the testing period, but the preference is to have all of the data from Phase 2 testing before making design changes that include installation of additional extraction wells. DEQ's October 1 comments included the request that contingency measure No. 6 be triggered during the test period, if needed. This request is further discussed in Section 5.3. During the August 15 workshop, DEQ requested that NW Natural evaluate the installation of passive DNAPL recovery wells near some of the

Upper Alluvium extraction wells. Installation of DNAPL recovery wells is addressed in Sections 4.2.1 and 5.3.

2.5 Provide a Calibration Dataset for HC&C Groundwater Model

A concomitant objective of the system testing is to provide the dataset needed to support a transient calibration and validation of the source control groundwater flow model. The *Hydraulic Source Control and Containment System Groundwater Model Update Report* (Anchor QEA 2013a), which is being submitted just prior to this report, provides details on model development and how data collected from startup tests will be applied for model calibration and validation. The HC&C Groundwater Model will be applied to illustrate capture at the selected ΔH 's and also to support the design of long-term monitoring at the site.

3 PHASED TEST PLAN

This Plan proposes significant revisions to the Extraction System Testing and Design Program that was described in Section 3.2 of the CDR. The plan in the CDR was estimated to occur over a period of weeks. This Plan will obtain data through a full seasonal range of river and groundwater elevation conditions to provide a representative evaluation of extraction system performance. This Plan includes a two-phase schedule of short-term tests followed by long-term tests that will last approximately 1 year. The information from the Phase 1 short-term tests will help inform parameters of the Phase 2 long-term tests.

In the October 1 comments, DEQ requested that their general comments be incorporated into this section of the Plan. All of DEQ's general comments have been incorporated in to the Plan; however, they were placed in the locations appropriate to the content of the comment, as listed below:

- DEQ's recommended list of data needs has been incorporated into Section 2.1 to set the stage for discussing data gathering objectives.
- DEQ's general criteria for collecting data have been incorporated into Section 3.1.
- DEQ's list of data gathering objectives has been incorporated into Section 2.2 because that section of the report covers the data objectives of the Plan. The application of the data objectives for the Phase 1 tests has been incorporated into Section 3.1.
- The use of hydraulic efficiency in the groundwater capture analysis has been incorporated into Section 5.1.1.
- The primary data gathering objectives for Phase 2 testing have been incorporated into Section 3.2.
- DEQ's requested DNAPL removal wells are discussed in Section 5.3.

In the October 1 comments, DEQ requested a description of the purpose and general approach to the currently ongoing process of shaking down the extraction and treatment system. The description (along with a list of primary components being operated and tested) will be provided in a memorandum to DEQ soon after submittal of this Plan.

3.1 Phase 1 Pre-Test

The Phase 1 pre-test consists of two parts: a 24 hour test involving the Upper Alluvium extraction wells, followed by a 1 week test combining the Upper Alluvium extraction wells with the remaining extraction wells in the system. A test of the Upper Alluvium extraction wells as a

subgroup was first requested by DEQ in a meeting on May 20, 2013. At the workshop, it was decided that the Phase 1 pre-test would begin by pumping the Upper Alluvium extraction wells as a subgroup for 24 hours with the set-point of -0.1 foot. After the 24 hour test the remaining extraction wells will be turned on and a 1-week test of all the extraction wells will be conducted at the set-point of -0.1 foot.

The purpose of the combined 24 hour and 1-week pre-test is to evaluate and establish design objectives for the Upper Alluvium extraction wells in Segment 1. At this time it is not intended that these data would be used for capture analysis. This limitation on the use of these data could change if it is later determined through analysis of the hydrology data that the magnitude of the 0.05-foot measurement error is larger than it should be.

3.2 Phase 1 Short-term Pump Tests

Following the pre-test, the Phase 1 pump tests will be short-term tests of all extraction wells. Each test will be conducted with control wells programmed for a different set-point. This series of tests will ideally be conducted from September through November 2013 when river levels are near typical seasonal lows with generally steady river flows. A primary goal of these tests is to select a set-point setting for the Phase 2 long-term tests to be conducted during the late winter and spring. Phase 2 tests are described in Section 3.2.

In the October 1 comments DEQ described the general criteria for collecting data during Phase 1 testing, as follows:

- Running each set-point test at least 1 week or longer to achieve quasi-steady state conditions between extraction wells, performance monitoring installations, and the Willamette River (i.e., sufficient time to establish water level elevation relationships and trends)
- Collecting water level data at a sufficiently high frequency to detect subtle, short-term inflections in well hydrographs indicative of a pumping response.

The hydrology data from the Phase 1 tests will be evaluated using the methods described in Section 5.1, with specific reference to data objective Nos. 1 through 6 described in Section 2.2. Subsequent to confirming objective No. 1 has been met, if one of objective Nos. 2 through 6 are not being met, then another test should be initiated using a higher set-point for one or more wells.

As described in the uncertainty analysis (Section 4.1.1.1), a total potential water level measurement error of 0.05 foot will be carried through the analysis of hydrology data. In the August 15 workshop, a discussion was held to determine how this potential measurement error will be accounted for in determining the set-points for the control wells. The magnitude of the error may mean that a set-point of -0.1 foot or less is not reliable enough to be used for capture analysis.

Following the pre-test, the next step will be to pump all of the extraction wells with a set-point of -0.15 foot. This test will be conducted for the purposes of hydraulic capture analysis and for DNAPL monitoring. The pumping portion of the test may be extended for another week. Factors that may cause an extension of the test period include changing river levels due to storm events, or technical issues with the equipment that require adjustments.

At the end of the set-point test of -0.15 foot, the wells may continue to be pumped at that set-point while hydrology data from that period of testing is evaluated. DEQ will be provided with a brief data report of the findings and recommendations for the next period of testing.

Based upon the findings from the -0.15 ΔH test, the ΔH would be increased for a 1-week test. For planning purposes, a set-point of -0.20 foot is anticipated for the next period of testing, but a higher set-point may be proposed based on the above results. At the conclusion of the test, another data memorandum will be provided to DEQ with either a recommendation for the test parameters for the Phase 2 long-term test (see Section 3.2) or to conduct another short-term test at a different ΔH .

As described in Section 2.2, if the hydrology data from one of the Phase 1 set-point tests meets the first six data objectives, subject to DEQ approval, the Phase 2 long-term test can be initiated at that setting.

3.3 Phase 2 Long-term Pump Test

As described in DEQ's October 1 comments, the primary data collection objective of the long-term testing phase is to assess the capacity of the HC&C system to achieve the first six data objectives (see Section 2.2) identified for the initial testing phase under seasonally changing groundwater and river stage conditions. The Phase 2 long-term test will be conducted from approximately January 2014 through August 2014. This period of the year typically sees the river go through its largest changes in stage from winter storm events through the spring and

early summer snow melt and dam releases followed by summer low flows and low stage. This period of testing is selected to assess system performance through these changes in river stage and groundwater elevation gradients. The long-term pump test will be conducted with the control well set-point selected from evaluation of data from short-term tests of all extraction wells described in Section 3.1. Depending upon the findings from previous tests, this long-term test may have some control wells programmed with slightly different set-points. The heterogeneous nature of the alluvium may cause the aquifer to respond differently between extraction wells, and slight adjustments to the set-point at individual control wells could be needed to achieve the optimum system operational condition. It is also possible that the control well set-point would be changed during the long-term test if data are indicating a change is needed to account for seasonal river or groundwater level changes.

4 DATA COLLECTION PLAN

4.1 Hydrology Data

4.1.1 Hydrology Data Uncertainties

DEQ's concerns about hydrology data uncertainties are described in an August 7, 2012 email (Bayuk 2012a). In its August 2012 correspondence, DEQ raised the following specific items of concern with the understanding that other areas of concern could arise later:

- Accuracy of the transducers and transducer drift
- Accuracy of electronic depth-to-water probes
- Accuracy of the site survey
- Daily tidal changes
- Seasonal river stage fluctuations
- Location and depth of a transducer-equipped installation relative to a control well/extraction well pair
- Use and reliability of the MODFLOW model for predicting small differences in water levels (e.g., on the order of a few tenths of a foot)

To address these issues, NW Natural provided DEQ with the February 13, 2013 memorandum, Uncertainty Evaluation for Control Wells of the Hydraulic Control and Containment System (Anchor QEA 2013b). For reference, that memorandum is provided with this Plan as Appendix A. DEQ provided comments to the February 13 memorandum in an April 23 email. DEQ, NW Natural, USEPA, and Siltronic then had a May 8 meeting where the comments in the April 23 email were discussed. DEQ then provided a May 15, 2013 email summarizing the May 8 meeting discussion, including DEQ's request for a written plan for conducting the initial phase of HC&C testing (this Plan). For reference DEQ's April 23 and May 15 emails are provided in Appendix B. DEQ, NW Natural, USEPA, and Siltronic had a May 20, 2013 meeting where NW Natural presented a summary of the HC&C testing plan, including objectives, schedule, data collection, data analysis, and model plans. The May 20 presentation also addressed how the test plan would generally address the uncertainty issues. For reference, the May 20 presentation is provided in Appendix B. All of this information was considered in preparing this Plan.

4.1.1.1 *Identification of Uncertainties*

Some of the key information from the February 13, 2013 memorandum on uncertainty is restated in this Plan. The set of uncertainty topics identified by DEQ and listed in Section 4.1.1, are grouped into the following three categories: 1) topics related to the accuracy of water level measurements; 2) topics related to river stage; and 3) topics related to data interpretation. A summary of the topics and findings from the uncertainty evaluation is presented in Table 1.

In its April 23, 2013 email comments to the February 13 memorandum, DEQ accepted conclusions summarized in Table 1 regarding errors associated with water level measurements. To account for those errors during system testing, NW Natural proposes to follow procedures outlined in Table 1 for all phases of testing and use a total potential error of plus or minus (\pm) 0.05 foot. The data collection plan in Section 4.1.1.2 describes field protocols that will be followed to maintain the hydrology data measurement accuracies stated in Table 1.

Regarding the conclusions in Table 1 that address river stage fluctuation, tidal fluctuations, transducer locations, and the MODFLOW model, DEQ requested further evaluation during the initial phase of testing. Evaluation of those issues is further addressed in Section 4.1.1.2 and subsequent sections of this Plan.

4.1.1.2 *Data Collection Plan*

The primary source of hydrology data to be used during the system pump tests is the water level transducers deployed in the Site's monitoring wells, extraction wells, piezometers, and the river. The transducer that monitors river level is at the Fuel and Marine Marketing (FAMM) dock and is wired to the PLC. Table 2 shows which monitoring wells, extraction wells, and piezometers are wired to the PLC. The other well transducers listed in Table 2 are not wired to the PLC, and during testing, data will be downloaded by field staff into portable data storage units.

As described in the Sampling and Analysis Plan (SAP; see Appendix C), there is a detailed field protocol for setting up and calibrating the transducers prior to each test. These protocols are designed to minimize error in setting up transducers. With regard to the accuracy of transducers and water-level probes, Table 1 lists the estimated uncertainty in feet. The estimated uncertainties related to water-level probe measurements, transducer drift, and the accuracy of the site survey will be combined into a total uncertainty of 0.05 foot for these three factors, as mentioned in the previous section.

Transducers are calibrated using electric water-level probes on several occasions during the test period. The first time they are calibrated is when they are installed in the well. Then they are calibrated again at the beginning and end of each pump test. Transducers that are showing excessive drift between calibrations will be removed for repair or replacement. Accuracy in the use of the electric water-level probes will be maintained by the field staff by making repeat measurements from a fixed reference point.

Transducers will be set up to measure water levels at 15-minute intervals for the Phase 1 tests described in Section 3.1. This is the same time interval used for past pump tests at the Site. During the August 15 workshop, DEQ requested that consideration be given to shortening the transducer water level measurement time interval for a subset of the monitoring wells during testing. Anchor QEA agreed that shortening the measurement time interval on a limited number of wells for a subset of the tests is feasible. DEQ provided Anchor QEA with a list of monitoring wells at which shorter measurement time intervals should be considered, as well as test durations over which the shorter measurement time intervals should be considered. Anchor QEA is currently in the process of installing transducers in each of the installations identified by DEQ. Higher frequency water level measurements (i.e., 1-minute intervals) will be collected at these installations for at least the duration of the Phase 1 testing period. The measurement frequency may be changed for Phase 2 long-term tests depending upon the results of data analysis of short-term tests. The transducer data storage capacity limit is reached faster with short-time intervals between readings. This is only a factor for those transducers that are not wired to the PLC. The advantage of increasing the time between measurements is that the time period between field data downloads can be increased for the transducers that are not wired to the PLC. The measurement frequency will not be increased if it would negatively affect data usability.

With regard to the other potential sources of uncertainty listed in Table 1, the following steps will be taken to evaluate those issues during the testing:

- **Seasonal river stage and daily tidal changes.** As stated in Table 1, river level changes due to river stage and tidal fluctuations are not believed to be a source of uncertainty because past tests at the Site have shown that the transducers in upland control wells accurately track these changes. However, to confirm this, Phase 1 short-term test hydrographs for all control wells will be used to determine the net gradient between a control well and the river (see Section 5.1.1.1.1). If any control well is found to display insufficient gradient to ensure groundwater control based on Phase 1 short-term tests,

possible solutions to this issue will be discussed with DEQ before the long-term testing is initiated.

- **Location and depth of transducer-equipped installation relative to a control well/extraction pair.** As stated in Table 1, this is not believed to be a significant source of uncertainty. The water level data will be used to create potentiometric surface maps for capture analysis. Model adjustments can be made to account for the location and depth of a water-level monitoring well relative to control wells and pumping wells. The success of such model adjustments will be evaluated during model calibration and validation after Phase 2 testing is complete.
- **Use and reliability of the MODFLOW model for predicting small differences in water levels.** As stated in Table 1, this uncertainty will be determined after Phase 2 testing, during model calibration and validation to hydrology data obtained from the pump tests. Uncertainty in model predicted water levels will be quantified through summary statistics (sums of squared errors and model-data correlation [R^2]) during the calibration and validation stages. As indicated earlier, the calibration and validation of the model will use data collected during Phase 1 of the testing to assist in establishing operational parameters for the Phase 2 test. Additional model validation during and following the Phase 2 test will be used to evaluate the effectiveness of the system for groundwater containments and assist in developing contingency actions if any are needed.

4.2 DNAPL Data

As described in Section 2.2, this Plan is designed to gather data to assess how DNAPL is reacting to operation of the extraction system. The design of the extraction well system was significantly modified with DEQ input in order to reduce groundwater gradients in the Upper Alluvium in Segment 1 and to minimize the potential for downward vertical migration of DNAPL. Mobile DNAPL is expected to migrate into Segment 1 extraction wells that are screened in mobile DNAPL. However, the reduced horizontal and vertical gradients that will result from the extraction well network are not expected to mobilize DNAPL beyond a distance of a few feet from each extraction well.

The DNAPL monitoring program that will be implemented during extraction system testing will be very similar to the monitoring program described in the January 2012 CDR (Anchor QEA 2012), as subsequently modified through various agreements with DEQ. The DNAPL monitoring program in the CDR was intended to be implemented during long-term

operation of the system. The DNAPL monitoring program consists of the following three main elements:

- Using TarGOST sampling methods
- Monitoring and recovery of DNAPL entering wells
- Monitoring of DNAPL entering the treatment system oil-water separators

These elements are described in the subsequent sections, followed by a summary of the reporting to be prepared for submittal to DEQ, which will document results and conclusions of the DNAPL monitoring program.

4.2.1 Using TarGOST Sampling Methods

TarGOST sampling methods will be used to monitor the migration of DNAPL into areas adjacent to the former effluent ponds where DNAPL has not been detected to date. The identification and selection of TarGOST monitoring areas is described in Section 3.2 of the CDR.

Three TarGOST monitoring areas (shown on Figure 4) have been selected for TarGOST sampling based on the following criteria:

- Previous borings in the area that have had no DNAPL observations in the Upper Alluvium
- Adjacent to the estimated extent of DNAPL in the Upper Alluvium
- Adjacent to source control extraction wells

An approximate 10-foot-by-10-foot portion of each zone has been selected for monitoring. These areas are shown on Figure 4 with an orange-colored square symbol. These areas were selected based on their proximity to extraction wells (areas closer to extraction wells will be targeted) and proximity to localized geological conditions that may increase the likelihood of DNAPL migration. The TarGOST monitoring areas shown on Figure 4 were proposed in a July 3 memorandum to DEQ, *Review of TarGOST Monitoring Areas* (Anchor QEA 2013c). DEQ reviewed the July 3 memorandum and conducted informal discussions with Anchor QEA about DEQ-recommended changes to the locations of the TarGOST monitoring areas. DEQ and Anchor QEA met at the Site on July 30 to view the DEQ-recommended locations in light of potential drilling equipment access issues and below ground utilities. The boring locations were staked in the field, pending underground utility checks. The TarGOST monitoring borings

were completed in August 2013. Figure 4 has been revised show the locations of the completed TarGOST monitoring area borings where DNAPL was not observed.

The three TarGOST monitoring areas will be retested for the presence of DNAPL in the Upper Alluvium at the 6-month and 1-year intervals following the beginning of extraction system testing. One TarGOST boring will be installed in each area within the triangle formed by the baseline borings.

In the event of DNAPL detection during TarGOST monitoring, the following assessment steps will be taken:

- Additional confirmation TarGOST boring will be advanced.
- If the confirmation boring does not show the presence of DNAPL, it will be assumed to be non-detect for DNAPL and that the previous detection was due to DNAPL that was already present at the time of the baseline borings. The TarGOST monitoring area will stay in the monitoring program, but the other steps described subsequently will not be taken. If confirmed, a push probe within the monitoring area to collect soil core across the depth of DNAPL detection will be advanced.
- The core will be shipped to a laboratory for physical description and photography under white light and UV light.
- Select subsamples from the core for DNAPL saturation and mobility testing will be tested.

Per DEQ's request on page 10 of the August 9, 2012 letter (Bayuk 2012b), TarGOST borings were also completed in August, 2013, near six extraction well locations prior to extraction well operation. The six extraction well locations being monitored were recommended by DEQ and include PW-2U, PW-3U, PW-5U, PW-6U, PW-11U, and MW-14U, shown on Figure 4. The purpose of these borings is to assess baseline DNAPL conditions near the extraction well to monitor possible lateral and vertical DNAPL migration during extraction well operation. Objectives of these six monitoring locations are different than the three proposed TarGOST monitoring areas previously described. DNAPL has been previously detected at these six locations, whereas DNAPL has not previously been detected in the other three TarGOST monitoring areas. For these six areas, the goal is to conduct borings on the same 6-month and 1-year schedule, but in this case, these results will be evaluated to determine if there is evidence of a measurable change in DNAPL thickness or depth compared to the baseline boring. The borings were advanced to a depth of 20 feet below the total depth of the extraction well to

detect and establish baseline conditions concerning the presence of DNAPL. Pursuant to the October 1 comments, DEQ evaluated the need to extend the depth of subsequent TarGOST borings deeper than 20 feet below the extraction well boring depth. Per DEQ's request, future TarGOST borings advanced near extraction well PW-2U be advanced to a depth of 147 feet, consistent with the depth drilled for the installation of PW-2L. The subsequent borings to be completed at 6 months and 1 year will be used to compare the nature and extent of DNAPL compared with the baseline boring. TarGOST borings will not be placed closer than a radius of 20 feet of the proposed extraction well and no farther than 30 feet. The minimum distance between the TarGOST boring and the extraction well is established to prevent the bentonite grout that will be injected during abandonment of the TarGOST boring from reducing the permeability of the soils in the immediate vicinity of the extraction well screen zone. The maximum distance is intended to minimize errors that would result from encountering heterogeneous distribution of DNAPL at the site.

4.2.2 *Monitoring and Recovery of DNAPL Entering Wells*

The low per-well pumping rate of approximately 5 to 10 gallons per minute (gpm) for each of the Upper Alluvium wells in Segment 1 is not expected to generate a high enough hydraulic gradient to cause DNAPL migration, with the exception of mobile DNAPL adjacent to the well screen, which would be recovered by the system. Nevertheless, all extraction wells have been designed to facilitate the collection and removal of DNAPL that enters the well. Each well is installed with a sump below the screen to collect DNAPL.

All extraction wells are equipped with air lines and a downhole port to accommodate an air-actuated DNAPL removal pump in the event that DNAPL is detected in the well sump. DNAPL removal pumps are in inventory at the Site, and a pump can be installed soon after a measurable DNAPL thickness is first detected in a sump. Manual and other pumping methods may be selected for DNAPL removal, as appropriate.

Typically, the air-actuated pumps will be manually operated by opening the air valve to remove DNAPL, as needed. If DNAPL production rates are high enough that manual operation of a DNAPL removal pump would need to occur more often than weekly, a cycle rate will be selected to allow operation of the pump continuously such that DNAPL thickness is maintained below the base of the screen. Alternately, other manual removal methods may be used to maintain DNAPL levels, such as pumping with a peristaltic pump or a Waterra Inertial Pump.

The frequency of DNAPL removal, where needed, will be based on the rate of DNAPL entry into the well. DNAPL will be removed from wells, to the extent practicable, and the volume will be recorded. The removal frequency will be monitored, so DNAPL thickness does not reach the top of the sump. DNAPL removed from each well will be containerized separately for each well, so a removal volume can be estimated for each well. Extraction wells will be monitored for DNAPL entry according to the schedule discussed at the end of this section.

Although DNAPL is not expected to enter control and monitoring wells, each monitoring well included in the system performance monitoring program will be monitored for DNAPL entry. Control wells will not be tested for DNAPL as originally shown in the CDR because each time the interface probe is lowered into a control well, it disturbs the water level, potentially disturbs the transducer, and would affect the water level data being recorded by the PLC. Monitoring wells, control wells, and piezometers installed as part of this program are also constructed with a sump below the screen.

DNAPL has been detected in several of wells along the shoreline in Segment 1, including some old wells and some new wells. These include MW-16-45, MW-18-30, MW-26U, MW-34L, MW-38U, PW-1-80, and PW-2L (see Figure 3). These wells are currently being monitored, along with the other wells listed in Table 3. Accumulated DNAPL is being removed from these wells and the volumes recorded, as described previously.

Extraction wells, monitoring wells, and piezometers are currently being monitored to develop a baseline of data under natural non-pumping conditions; however, it should be noted that DNAPL entry into some on-site monitoring wells under natural gradients was first observed several years after installation. Thus, the presence of DNAPL in a control or monitoring well during system operation does not in itself indicate that the source control system is causing DNAPL to enter the well.

Upon system startup for Phase 1 testing and thereafter during testing, the extraction and monitoring wells listed in Table 3 will be closely monitored for DNAPL entry. DNAPL monitoring will occur before the start of the first Phase 1 pump test described in Section 3.1. During the Phase 1 and Phase 2 test period, the DNAPL monitoring schedule will be as follows:

- Daily monitoring will occur for the duration of the pre-test described in Section 3.1. After the DNAPL data from the pre-test is evaluated, a proposal will be made to DEQ on the frequency of DNAPL monitoring for the remainder of the testing program.

Observations of DNAPL entry and DNAPL removal volumes will be included in the DNAPL monitoring reporting discussed later in this section.

4.2.3 *Monitoring of the Oil-water Separators*

The low per-well pumping rate of approximately 5 gpm for each of the Upper Alluvium wells in Segment 1 is not expected to generate a high enough hydraulic gradient to cause DNAPL migration, with the exception of mobile DNAPL adjacent to the well screen, which would be recovered by the system. Thus, DNAPL entering a well is expected to collect in the well sump and not be pulled into the pumping system itself. DNAPL that does enter the system through well pumps will be recovered in oil-water separators at the beginning of the treatment system.

The ability to accurately measure the DNAPL that accumulates in the oil-water separators is uncertain at this time. The feasibility of making accurate measurements of the volume and rate of DNAPL accumulation will be evaluated during startup and testing of the HC&C and treatment systems. If it does seem to be feasible, discussions will be held with DEQ to assess if this information may be useful for DNAPL monitoring.

The amount of DNAPL collected in each oil-water separator will be observed and recorded as part of routine monitoring of the treatment system performance. As necessary, DNAPL will be removed from these separators and disposed of off site. The estimated amount of DNAPL observed in and removed from the system for off-site disposal (if any) during each monitoring period will be included in the DNAPL monitoring reporting discussed in the following section.

4.2.4 *DNAPL Monitoring Reporting*

Data from the previously described groundwater well monitoring and oil-water separator monitoring activities will be included in the data reports to be submitted to DEQ, as listed in Section 6.

A DNAPL Monitoring Report will be prepared for submittal to DEQ, following completion of the 6-month and 1-year TarGOST monitoring events. These two reports will be part of the Phase 2 Interim and Final Data Reports listed in Section 6. These reports will summarize the results for the DNAPL monitoring activities, including a trend analysis of the data.

4.3 Water Quality Data

Groundwater quality trends will be monitored at selected wells during Phase 2 testing of the source control system. The details of the water quality monitoring program for this Plan are in Table 3. The water quality monitoring program in this Plan is similar to the water quality monitoring plan described in the January 2012 CDR, as later modified in agreements with DEQ. The water quality monitoring plan in the CDR was intended to be implemented for long-term operation of the system but is applicable to this Plan.

Because both upland and nearshore groundwater is contaminated with the same constituents of interest (COIs) at similar concentrations, there is no chemical plume boundary. In addition, there is currently not a water quality compliance boundary to assess. The groundwater quality data will be used to measure water quality changes that occur during extended testing and operation of the extraction well system.

The HC&C system is being implemented as an element of groundwater source control (i.e., an element of a groundwater removal action) in part, to prevent contaminated groundwater in the Alluvium WBZ from migrating to the river. Although site-specific groundwater quality compliance criteria are not currently established, DEQ has indicated that they will likely be set in the future based on the outcome of the ongoing uplands Remedial Investigation/Feasibility Study.

DEQ did not approve the May 2011 *Draft Groundwater Source Control Final Design Report* (FDR; Anchor QEA 2011) proposals that the shoreline area monitoring wells that are currently sampled twice per year be reduced to annual sampling or that the planned extraction wells be used for water quality trend monitoring purposes. In DEQ's September 22, 2011 comment letter, DEQ requested that the current semi-annual well sampling program be continued. It also requested that other changes be made to the proposed performance monitoring program. The program requested by DEQ is described in the remainder of this section.

Table 3 lists components of the monitoring plan to be implemented within 3-months of initiating the Phase 1 pre-test, including newly constructed and previously existing shoreline monitoring wells, piezometers, observation wells, and extraction wells. The field sampling procedures, sample handling protocols, analyte testing, and quality assurance/quality control plans are described in detail in the SAP (see Appendix C) and are consistent with sampling work conducted previously.

The previously existing shoreline monitoring wells are sampled semi-annually in the current upland monitoring program. With the addition of the new wells shown in Table 3, the FDR proposed that the sampling frequency for existing wells be reduced to annual for the next 5 years. This reduction is justified because the newly constructed wells provide additional spatial coverage of the shoreline zone, which makes semi-annual monitoring of the currently existing wells unnecessary. After 5 years of source control operation, the monitoring program would be evaluated to determine if continued monitoring of previously existing wells is needed. In the September 22, 2011 letter attachment, DEQ did not approve the proposed reduction in monitoring frequency and instead proposed that the first semi-annual sampling round of existing and newly constructed wells occur within 3 months of extraction system startup, and the second round would occur within 6 months of system startup. For this purpose, system startup is defined as the initiation of the Phase 1 pre-test described in Section 3.1. DEQ requested this approach for the first year of operation to enable evaluation of the effects of pumping on water quality trends in monitoring wells. Under this DEQ-recommended approach, both of the semi-annual sampling events will occur within 6 months of startup of the beginning of Phase 1 pre-test.

DEQ also requires four quarterly sampling rounds of all newly constructed wells to develop a baseline of data. NW Natural completed the first quarterly sampling round of new wells in June 2013. The second quarterly round of testing for new wells was conducted in September 2013. As described previously, the next groundwater monitoring event is scheduled to occur within 3 months of extraction system startup of Phase 1 testing and will follow the performance monitoring plan shown in Table 3. The routine monitoring program that is currently conducted by Hahn and Associates, Inc., will also be conducted at this time.

Due to the very high expense of sampling and laboratory testing of groundwater from the large number of new and previously existing wells, NW Natural wants to make sure that there is commensurate value in data before completing the third round of sampling at new wells and second semi-annual sampling of old wells. NW Natural will evaluate the groundwater quality data at the completion of the sampling event conducted within 6 months of system startup to determine the usability of the data for evaluating the performance of the source control system. Following that review, NW Natural will likely submit a report to DEQ and propose revisions to the monitoring plan.

Newly installed wells listed in Table 3 are divided into those with a recommended tiered monitoring frequency and those with a semi-annual monitoring frequency. Extraction wells at all 14 locations will be on the tiered monitoring plan. Extraction wells in the tiered plan will be sampled monthly for the period of Phase 2 testing.

Based on the DEQ March 26, 2010 comment letter, the source control groundwater quality trend monitoring program will be expanded to include the following elements:

- Field samplers will test for pH, specific conductance, temperature, oxidation reduction potential (ORP), and turbidity as part of the sampling process. Per DEQ's request on page 11 of the September 22, 2011 letter attachment, field measurements of sample turbidity have been added to the SAP (see Appendix C).
- DEQ recommended that all constituents on the groundwater permit discharge list and any constituents that could affect the operation of the extraction/treatment system be tested. As approved by DEQ in the September 22, 2011 letter, this will be accomplished by testing the combined influent to the treatment system instead of each well in the monitoring program. Sampling individual wells could be considered if an analyte is detected in the combined influent that is deemed to be an issue for the treatment system.

1,2,4-trimethylbenzene and 1,3,5-trimethylbenzene have been added to the volatile organic compound (VOC) reporting list.

DEQ requested that inorganic indicators of river water be added to the testing program, including calcium, potassium, sodium, iron (total and dissolved), magnesium (total and dissolved), sulfate, chloride, bicarbonate, carbonate, and nitrate. Based on DEQ's approval in the September 22, 2011 letter, the plan was to sample each extraction well weekly during the first month of Phase 2 testing, with the samples to be tested for the analytes recommended by DEQ. DEQ's response to this approach in its August 2012 (Bayuk 2012b) letter says "Upon further consideration DEQ approves limiting sampling and analysis of "river parameters" to piezometers constructed in the alluvium water bearing zone (WBZ). For the first year of HC&C system operation, DEQ requests "river parameters" to be analyzed for on a monthly basis. Based on review of the first year of data and pending DEQ's approval, the sampling frequency may be modified".

Since last year, NW Natural has had significant experience with access problems and the resulting cost of monitoring and sampling the river edge piezometers. It has been found that

sampling piezometers at the river's edge is quite difficult and costly due to changing river levels and the need to use a boat during some periods of the year. For the test program NW Natural requests DEQ to reconsider this request to do monthly sampling of the river piezometers for river parameters and to reestablish the previous approach of sampling extraction wells for river parameters. This topic was discussed during the August 15 workshop, and DEQ indicated that it would be acceptable to sample the extraction wells for this purpose; however, DEQ pointed out that the extraction well data would not provide as early of a detection of river water infiltration as the shoreline piezometers would. Based on the discussion during the workshop, the current plan is to reestablish the previous approach of sampling the extraction wells for river parameters. DEQ approved this approach in their October 1 comments.

DEQ's September 22, 2011 letter attachment, also requests that metals and total cyanide be added to the analyte list and that available cyanide be tested instead of weak acid dissociable (WAD) cyanide. This request has been incorporated in the plan for the first year of system testing and operation as follows:

- USEPA Method 8260 for VOCs
- USEPA Method 8270 Selective Ion Monitoring (SIM) for polycyclic aromatic hydrocarbons (PAHs) and 1-methylnaphthalene, 2-methylnaphthalene, dibenzofuran, and carbazole
- USEPA Method 335.4 for total cyanide
- USEPA Method OIA-1677 for available cyanide
- USEPA Method D-4282 for free cyanide
- USEPA Method 6000 Series for total metals

The DEQ-requested monitoring of PAHs, VOCs, metals, total cyanide, free cyanide, and available cyanide will provide a comprehensive picture of the trends of water quality changes that occur during testing of the extraction/treatment system. After the first year of system testing and operation, the monitoring program will be evaluated to determine if the scope of monitoring can be reduced without affecting the ability of the source control system to meet its hydraulic containment goals.

4.4 Treatment System Sampling

During Phases 1 and 2 of the testing program, a water quality and waste stream monitoring program will be conducted at the groundwater treatment system. This monitoring will begin

with the Phase 1 pre-test and will occur at the NW Natural pre-treatment plant, the Siltronic pre-treatment plant, and the main treatment plant. The details of the monitoring program were provided to DEQ in an October 23, 2013 email, which is provided in Appendix B4 for reference.

5 DATA ANALYSIS PLAN

5.1 Assess System Operational Parameters

5.1.1 Groundwater Capture Analysis

The groundwater capture analysis will consist of a combination of Phase 1 and 2 testing data analyses and groundwater flow modeling analyses. Primary data used for groundwater capture analysis will be water-level data collected by transducers at the network of HC&C monitoring wells during Phase 1 and 2 testing. Data from these wells will be used in a combination of contouring groundwater levels, hydrographs, and gradients. The HC&C groundwater model introduced in Section 2.5 will be used (after calibration) to simulate groundwater levels and velocities at the set-point values selected over the short-term (Phase 1), as well as long-term (Phase 2) testing periods. Model predictions of water levels and velocities will be used to support a series of analyses described below that would help support evaluations of groundwater capture.

As described in Section 3.1, the hydrology data from the Phase 1 tests will be evaluated with specific reference to data objective Nos. 1 through 6 described in Section 2.2. The data analyses described in Sections 5.1.1.1 through 5.1.1.1.2 will be conducted to assess the six data objectives. Subsequent to confirming objective No. 1 has been met, if one of objective Nos. 2 through 6 is not being met, then another test will be initiated using a higher set-point for one or more wells.

In the October 1 comments, DEQ requested that the monitoring wells and piezometers be categorized according to hydraulic efficiency. Table 3 has been revised to include a new column that subdivides the wells into those with high, low, and minimal relative efficiency. The wells are placed into these categories based on the hydrogeologic unit of the screen zone. These categories will be used to evaluate the groundwater capture performance with respect to data gathering objective Nos. 3 through 6 listed in Section 2.2. As discussed in the October 7 conference call, this list is considered a starting point for the well categories, and some of the wells may be re-categorized after evaluating the hydrology data from the Phase 1 tests.

5.1.1.1 Potentiometric Surface Contour Maps

Potentiometric surface maps will be developed using both water level data and output from the groundwater flow model. The maps will be used to evaluate groundwater capture within the immediate vicinity of the HC&C system.. For each set-point test, the hydrology data will also be evaluated using hydrographs to determine if the ΔH at each of the measuring points meet

the criteria described in data objectives 1 through 6. For this analysis, the ΔH will be compared with the relevant criteria at each of the high, low, and minimal wells according to their hydraulic efficiency rating. In addition to hydrographs and contour maps, the groundwater flow model will be used to supplement evaluation of capture offshore from the HC&C system and in the deep Alluvium WBZ.

5.1.1.1.1 Serfes Gradient Contour Maps

Due to tidal influences at the Site and the frequency of water level data collection, water level data will be averaged to produce water level contours and gradients that are representative for a period of time. The averaging method will be a 3-day rolling average based on the method presented by Serfes (1991).

During the August 15 workshop, DEQ requested an evaluation of whether the Serfes averaging method will increase the potential error. The error is the average of the individual errors on all the measurements. Because the same theoretical error of 0.05 foot occurs on each water level measurement, the error is the same (i.e., $N * 0.05/N$, where N is the number of measurements), so averaging does not exacerbate the error.

Capture will be determined by average gradients over a 3-day period. During the workshop, DEQ requested an example of how the Serfes method will be used and also requested a backup spreadsheet for a well. To address this request, the spreadsheet from testing of the Segment 2 extraction wells is included in Appendix A. Because of the large file size, this file is provided on a CD to the agencies. The formulas used in the Serfes averaging method are imbedded in the spreadsheet and may be viewed for further details.

The average groundwater levels will be used to prepare groundwater contour maps for the upper and intermediate Alluvium WBZ. Contours will be used to demonstrate inward gradients from the river to the HC&C system.

As described in Section 5.1.1.1, for each set-point test, the hydrology data will be evaluated using hydrographs to determine if the ΔH at each of the measuring points meet the criteria described in data objective Nos. 1 through 6. The Serfes Method and hydrographs will be compared with the relevant criteria to determine whether the data collection objectives #4 and #6 have been met.

5.1.1.1.2 Vertical Gradient Contour Maps

Groundwater contours will be used to develop areal distributions of vertical gradients between the shallow and intermediate Alluvium WBZ. These will be prepared as contours of vertical gradients.

Vertical gradients between the intermediate and deep Alluvium WBZ will be determined on a well-to-well basis where deep Alluvium WBZ wells are available. Vertical gradients from the deep Alluvium WBZ will also be computed between deep Alluvium WBZ wells and the river. The groundwater flow path from the deep Alluvium WBZ will be determined by the stronger gradient between the deep Alluvium WBZ wells and either the intermediate Alluvium WBZ wells or the river. The details of the gradient calculations, including estimation of the flowpath length, will be provided to DEQ in the initial data evaluation submittal.

For each Phase 1 set-point test, hydrology data will be evaluated using hydrographs to assess whether set-point changes measurably influence installations located near the northern and southern margins of the performance monitoring network, wells in the Upper Alluvium, wells in the deep portions of the Lower Alluvium, and offshore piezometers. As indicated in Section 5.1.1.1, the groundwater flow model will also be used to supplement evaluation of capture offshore from the HC&C system and in the deep Alluvium WBZ.

5.1.1.2 Particle Tracking

The calibrated groundwater flow model will be used in a particle tracking analysis to illustrate the boundaries of the HC&C capture zone. During the workshop, it was agreed that the capture zone analyses will be performed for the average condition that will be present during the testing.

5.1.1.3 Water Budget Analysis

The groundwater flow model will be used to show the groundwater flow relationship among the fill, upper, intermediate, and deep Alluvium WBZs and the HC&C system. This will illustrate how groundwater flows from the model boundaries through the WBZs and either to the HC&C system or to the river.

5.1.1.4 *Fill WBZ*

Groundwater elevation data from monitoring wells screened in the Fill WBZ will be plotted on hydrographs for all pump tests to be completed in this Plan. The primary purpose will be to determine how the fill WBZ groundwater elevations are being affected by pumping extraction wells in the alluvium. The long-term testing described in Section 3.2 will provide an indication of the ability of the alluvial WBZ extraction system to dewater the fill WBZ.

As described in Sections 5.1.1.1 and 5.1.1.1.1, for each set-point test, the hydrology data will be evaluated using hydrographs to determine if the ΔH at each of the measuring points meet the criteria described in data objective No. 6. For this analysis, fill monitoring wells and piezometers will be considered to have a minimal hydraulic efficiency, as shown in Table 3.

5.1.2 *Analysis of ΔH and Hydraulic Gradients*

The purpose of this analysis will be to evaluate how the control well set-point affects groundwater hydraulic gradients in the alluvium. This analysis will also support the evaluation of DNAPL described in Section 5.2. For this analysis, a subset of nearby monitoring wells will be selected to evaluate with each control well. A list of the monitoring wells to be evaluated will be provided for DEQ review before the beginning of testing. The monitoring wells will be selected based on their location near the margins of the monitoring network (i.e., deep monitoring wells and offshore piezometers). These wells will be selected for their suitability for calculating vertical and horizontal gradients within the alluvium. For each set-point the resulting ΔH at the associated nearby monitoring wells and piezometers will be plotted. For each set-point, the resulting vertical and horizontal gradients from the associated monitoring wells will also be calculated and plotted.

5.2 *Assess Effects of Pumping on DNAPL*

As described in earlier sections of this Plan, DEQ requested that the extraction system be designed and operated to balance the two goals of groundwater capture and minimization of potentially problematic DNAPL migration. This analysis will use the hydrology data and DNAPL monitoring data to evaluate the effects on DNAPL occurrence and movement.

5.2.1 *DNAPL Recovery*

For this analysis, DNAPL recovery rates from extraction and monitoring wells will be plotted over time for each pump test. As mentioned previously, DNAPL will be removed from these

wells at a rate that will prevent the well sump from being filled with DNAPL. This will facilitate an evaluation of DNAPL recovery rates at each well for each set-point. This will also allow a comparison of the possible changes in DNAPL recovery rates as the set-points are adjusted for each pump test.

5.2.2 TarGOST Data

As described in Section 4.2, the baseline borings in the three TarGOST monitoring areas were completed in August 2013. Then the TarGOST monitoring borings will be completed at the 6-month and 1-year intervals of the testing program per the Plan. These data will be used as part of the DNAPL migration assessment described in the next subsection.

5.2.3 DNAPL Migration Assessment

This assessment will consider DNAPL recovery time trend data in conjunction with TarGOST data to determine if potentially problematic DNAPL migration is indicated. For the purpose of this Plan, the potential for problematic DNAPL migration would be indicated by the following DNAPL monitoring results:

- The new appearance of measurable DNAPL in the sump of a monitoring well or piezometer located between extraction wells and the river
- The new appearance of DNAPL in one of the TarGOST monitoring areas
- DNAPL appearance in a TarGOST boring at depth interval(s) not previously observed near extraction wells

If one of these results occur during the testing period, this will trigger an analysis of DNAPL monitoring data in conjunction with the groundwater gradient and time-trend DNAPL removal data for the monitoring area.

At most DNAPL sites, DNAPL recovery rates decline rapidly with time, and the Site is expected to have similar DNAPL recovery trends. If DNAPL is detected in an area where the baseline TarGOST boring did not previously detect DNAPL, then the subsequent TarGOST monitoring steps outlined in Section 4.2 will be taken.

5.3 Assess Need for Contingency Measures

As described in Section 2.3, the six types of contingency measures being considered are as follows:

1. Adjusting pumping parameters
2. Adjusting the depth of the pump intake in an extraction well
3. Changing monitoring wells that are being used as control wells
4. Adjusting the performance monitoring sampling and analytical program
5. Installing DNAPL extraction wells
6. Adding groundwater extraction wells

Contingency measure Nos. 1 through 5 could be triggered during the testing period. The need for contingency measure No. 6, additional groundwater extraction wells, will be based on the groundwater capture analysis described in Section 5.1.1. The capture assessment will preferably include all of the seasonal conditions that will be encountered during the Phase 2 test. In the October 1 comments, DEQ requested that contingency measure No. 6 be triggered during the Phase 2 long-term testing period, if indicated by the data. NW Natural is willing to add extraction wells after at least 2 months of Phase 2 long-term test data have been evaluated if NW Natural agrees that the data clearly show that additional extraction wells are needed. If the data are not conclusive on this issue, NW Natural prefers to make this design change based on all of the Phase 2 testing data.

As discussed during the August 15 workshop, contingency No. 2 could include changing the depth of the submersible pump to allow more available drawdown. Most of the extraction well pumps are set above the top of the well screen and could be lowered to deeper depths within the well screen. This contingency could be triggered if a higher pumping rate and additional drawdown capacity is needed to achieve the higher discharge rate.

The changing of control wells would potentially be needed if the currently selected control well is not adequately representing conditions in that portion of the shoreline. The need for this contingency will be primarily based on the analysis of ΔH and gradients described in Section 5.1.2.

Contingency No. 4 is included in the event that a change in the monitoring program is proposed to DEQ based on review of the monitoring data. This potential to propose a change is discussed in Section 4.3.

Prior to the August 15 workshop, the plan was to evaluate the need for DNAPL extraction wells based on the DNAPL migration assessment described in Section 5.2.3. As mentioned in

Sections 2.3 and 4.2.1, DEQ requested consideration of existing DNAPL data to determine if passive DNAPL recovery wells should be installed early in the testing program, rather than waiting until the DNAPL migration assessment is completed. That evaluation has been conducted and the findings are summarized as follows:

- Review of DEQ's June 28, 2012 email and recent data on DNAPL occurrence resulted in consideration of three potential areas for installation of DNAPL removal wells near extraction wells PW-6U, PW-14U, and PW-11U. Based on boring logs and TarGOST data, DNAPL is present in the Upper Alluvium above these three extraction well screens.
- There is a small amount of room for a drill rig to install passive removal wells near extraction wells PW-6U, PW-14U and PW-11U. Figures 2b and 2c have been modified to show the locations where removal wells could be installed near these two wells. These locations are the general locations staked by Anchor QEA and DEQ on October 30, 2013. These locations were not surveyed, so the locations on the map are approximate and the borings will be advanced as marked in the field. Two locations were marked at PW-11U; DEQ will select one of the two locations before drilling begins.
- The DNAPL wells were designed through telephone calls and email exchanges with DEQ. The final selection of the well screen lengths and depths of the filter pack sand is documented in DEQ's October 23, 2013 email in Appendix B5.
- DNAPL removal wells will be installed near PW-6U, PW-11U, and PW-14U under the following conditions:
 - Due to the time it will take to schedule a drilling contractor, obtain the well construction materials, tanks, pumps, and other equipment, it is not possible to install these wells before the start of the Phase 1 test. These wells would be installed as early in the Phase 1 portion of the testing plan as feasible based on contractor and material availability.
 - These removal wells would be installed as 6-inch-diameter wells with stainless steel wire-wrapped screens. The borings would not be logged and samples would not be obtained during drilling because multiple borings have been previously completed at these locations. The same drilling and installation methods used for the groundwater extraction wells would be used to install these wells.
 - During the October 30, 2013 site walk with DEQ, a new baseline TarGOST monitoring site was selected that meets the criteria for extraction well PW-6U.

5.4 Uncertainty Analysis

As described in Section 4.1.1, data will be obtained during tests to allow evaluation of the uncertainties identified by DEQ. Hydrology data and measurement uncertainty information from Table 1 will be reviewed to see if the total potential error of ± 0.05 foot is appropriate to account for potential error in water level measurements. The hydrographs described in Section 4.1.1.2 will be reviewed to see if any control wells are displaying time lag that is significantly higher than the other control wells.

The HC&C groundwater model adjustments can be made to account for potential uncertainties, such as excessive time lag, that result from the location and depth of monitoring wells. The uncertainty analysis will be conducted during calibration and validation of the model and will also evaluate the ability of the model to predict small differences in groundwater levels during system operation. The approach to that analysis is described in the *Hydraulic Source Control and Containment System Groundwater Model Update Report*, which was submitted to DEQ on July 29, 2013.

6 SCHEDULE

The following schedule is planned for the system testing and reports to DEQ:

- **Phase 1.** Short term tests of all extraction wells from October through December 2013
 - Step 1, Upper Alluvium extraction well test at set-point -0.1 foot: 24 hours
 - Step 2, all extraction well test at set-point -0.1 foot: 1 week
 - Step 3, all extraction well test at set-point -0.15: 1 week
 - Data report to DEQ: 4 weeks from completion of the test
 - DEQ review: 4 weeks

The extraction well system water levels will be allowed to fully recover prior to steps 1 and 3. The initial data report will be used to determine whether the data collection objectives of steps 1, 2, and 3 have been met. If the data collection objectives have not been met, some or all of the testing may need to be repeated.

- Step 4, all extraction well test at set-point -0.20 foot: 1 week or longer to achieve quasi-steady state conditions
 - Data report to DEQ: 3 weeks from completion of the test
 - DEQ review: 3 weeks

Phase 2. All extraction well test using set-point(s) selected based on Phase 1 tests from January through August 2014

- Interim data report to DEQ 4 months from test start
- Final data report to DEQ 2 months from test end

7 REFERENCES

- Anchor QEA (Anchor QEA, LLC), 2011. *Draft Groundwater Source Control Final Design Report*. NW Natural Gasco Site. Prepared for NW Natural. May 2011.
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- Anchor QEA, 2013a. *Hydraulic Source Control and Containment System Groundwater Model Update Report*. NW Natural Gasco Site. Prepared for NW Natural. July 2013.
- Anchor QEA, 2013b. *NW Natural Gasco Site – Uncertainty Evaluation for Control Wells of the Hydraulic Control and Containment System*. Prepared for Oregon Department of Environmental Quality. February 15, 2013.
- Anchor QEA, 2013c. *Review of TarGOST Monitoring Areas*. Gasco Site. Prepared for Oregon Department of Environmental Quality. July 3, 2013
- Bayuk, D. (DEQ), 2011. Letter regarding: Draft Groundwater Source Control Measures Final Design Report Shoreline Segments 1 and 2, NW Natural Property and the Northern Portion of the Siltronic Corporation Property Portland, Oregon ECSI Nos. 84 and 183. September 22, 2011.
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TABLES

Table 1
Summary of Potential Sources of Uncertainties in the Accuracy of Groundwater Level Data Identified by DEQ

Potential Sources of Uncertainty	Estimated Uncertainty (feet)	Comments
Accuracy of the transducers and transducer drift	± 0.015	<p>The accuracy of transducers is determined by the range of water levels and resolution of the instruments. This is determined from the manufacturer's specifications.</p> <p>The transducer accuracy will be documented at the time of installation by calibrating to a manual water-level measurement.</p> <p>Drift will be determined from periodic hand measurements, usually at the time that transducer data are downloaded. Transducer readings are corrected accordingly, and any adjustments or replacement of transducers will be made in the field.</p>
Accuracy of electronic depth-to-water probes	± 0.02	Depth-to-water probes have been the industry standard for more than 30 years and their performance is well established. Accuracy is largely dependent on the operator. Operator error will be minimized by having multiple readings from a fixed reference point before recording.
Accuracy of the Site survey from which groundwater elevations are determined	Approximately 0.01	A level closure survey has been completed at Site wells, and the accuracy of the final closure was 0.01 feet.
Daily tidal changes	Not a source of uncertainty	The variable rate pumping test conducted in April 2012 indicated that control wells could accurately track fluctuations due to tidal changes.
Seasonal river stage fluctuations	Not a source of uncertainty	The variable rate pumping test conducted in April 2012 indicated that control wells could accurately track fluctuations in river stage.
Location and depth of a transducer-equipped installation relative to a control well/extraction well pair	Not a significant source of uncertainty	If necessary, model adjustments will be made to account for the location and depth of a water-level monitoring well relative to control wells and pumping wells.
Use and reliability of the MODFLOW model for predicting small differences in water levels	To be determined	This uncertainty will be determined during model calibration to HC&C startup data.

Notes:

DEQ = Oregon Department of Environmental Quality

HC&C = hydraulic control and containment

Table 2
Well Contruction Details

Well Number	Water-Bearing Zone	Date Installed	Date Decomm-issioned	Installation Method	Monument Type	Screen Type	Slot Size	Sand Pack	Well Diam.	Ground Surface	Top of Casing		Pump Inlet		Top Screen		Base Screen		Well Depth	
							(inches)	(Colorado)	(inches)	(feet COP)	(feet COP)	(feet bgs)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)		
Existing Monitoring Wells																				
MW-1-22	Surficial Fill	10/24/95	-	Hollow-Stem Auger	Above-grade	Slotted PVC	0.020	10-20	2	32.0	34.75	(2.7)	NA	NA	11.0	21.0	21.0	11.0	22.0	10.0
MW-1-55	Alluvial	7/10/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	33.1	35.64	(2.5)	NA	NA	45.0	-11.9	55.0	-21.9	57.0	-23.9
MW-1-82	Alluvial	7/9/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	33.5	35.95	(2.5)	NA	NA	72.0	-38.5	82.0	-48.5	84.0	-50.5
MW-2-32	Surficial Fill	11/6/95	-	Hollow-Stem Auger	Flush	Slotted PVC	0.020	10-20	2	34.8	34.41	0.4	NA	NA	21.5	13.3	31.5	3.3	32.5	2.3
MW-2-61	Alluvial	10/8/98	-	Hollow-Stem Auger	Flush	Slotted PVC	0.020	10-20	2	34.7	34.33	0.4	NA	NA	50.0	-15.3	60.0	-25.3	61.5	-26.8
MW-2-104	Alluvial	6/25/07	-	Sonic	Flush	Continuous wrap stainless steel	0.020	10-20	2	34.9	34.80	0.1	NA	NA	94.0	-59.1	104.0	-69.1	106.0	-71.1
MW-3-26	Surficial Fill	11/2/95	-	Hollow-Stem Auger	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.2	34.04	(2.8)	NA	NA	15.0	16.2	25.0	6.2	26.0	5.2
MW-3-56	Alluvial	11/1/95	-	Hollow-Stem Auger	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.2	34.02	(2.8)	NA	NA	45.0	-13.8	55.0	-23.8	56.0	-24.8
MW-4-35	Surficial Fill/Alluvial	10/31/95	-	Hollow-Stem Auger	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.7	34.44	(2.7)	NA	NA	24.0	7.7	34.0	-2.3	35.0	-3.3
MW-4-57	Alluvial	10/30/95	-	Hollow-Stem Auger	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.7	34.48	(2.8)	NA	NA	46.0	-14.3	56.0	-24.3	57.0	-25.3
MW-4-101	Alluvial	10/16/98	-	Dual Wall Reverse Air	Above-grade	Slotted PVC (pre-pack)	0.010	20-40	2	31.8	34.26	(2.5)	NA	NA	89.5	-57.7	99.5	-67.7	101.0	-69.2
MW-5-32	Surficial Fill/Alluvial	10/27/95	-	Hollow-Stem Auger	Above-grade	Slotted PVC	0.020	10-20	2	25.1	27.72	(2.6)	NA	NA	21.0	4.1	31.0	-5.9	32.0	-6.9
MW-5-100	Alluvial	10/23/98	-	Dual Wall Reverse Air	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	25.4	27.27	(1.9)	NA	NA	88.0	-62.6	98.0	-72.6	100.0	-74.6
MW-5-175	Alluvial	10/22/98	-	Dual Wall Reverse Air	Above-grade	Slotted PVC (pre-pack)	0.010	20-40	2	25.2	27.12	(1.9)	NA	NA	163.0	-137.8	173.0	-147.8	175.0	-149.8
MW-16-45	Alluvial	7/20/04	-	Sonic	Above-grade	Slotted stainless steel	0.010	10-20	2	30.8	33.10	(2.3)	NA	NA	30.0	0.8	45.0	-14.2	47.5	-16.7
MW-16-65	Alluvial	7/19/04	-	Sonic	Above-grade	Slotted stainless steel	0.010	10-20	2	30.6	33.13	(2.5)	NA	NA	55.0	-24.4	65.0	-34.4	67.5	-36.9
MW-18-30	Surficial Fill	2/27/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.7	34.18	(2.5)	NA	NA	19.0	12.7	29.0	2.7	30.0	1.7
MW-18-125	Alluvial	4/22/10	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.9	34.57	(2.6)	NA	NA	115.0	-83.1	125.0	-93.1	126.0	-94.1
MW-18-180	Alluvial	2/26/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.7	33.81	(2.1)	NA	NA	170.0	-138.3	180.0	-148.3	181.0	-149.3
MW-19-22	Surficial Fill	3/6/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	27.4	29.72	(2.3)	NA	NA	12.0	15.4	22.0	5.4	23.0	4.4
MW-19-125	Alluvial	3/12/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	27.2	29.33	(2.1)	NA	NA	115.0	-87.8	125.0	-97.8	126.0	-98.8
MW-19-180	Alluvial	3/2/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	27.3	29.73	(2.4)	NA	NA	170.0	-142.7	180.0	-152.7	181.0	-153.7
MW-20-120	Alluvial	3/8/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	25.6	27.69	(2.1)	NA	NA	110.0	-84.4	120.0	-94.4	121.0	-95.4
MW-21-12	Surficial Fill	7/6/07	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	20.3	23.16	(2.8)	NA	NA	7.0	13.3	12.0	8.3	14.0	6.3
MW-21U	Alluvial	9/24/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	20.5	22.38	(1.9)	NA	NA	25.0	-4.5	35.0	-14.5	38.0	-17.5
MW-21-75	Alluvial	7/5/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	20.4	23.03	(2.6)	NA	NA	65.0	-44.6	75.0	-54.6	77.0	-56.6
MW-21-115	Alluvial	7/2/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	20.5	23.35	(2.8)	NA	NA	105.0	-84.5	115.0	-94.5	117.0	-96.5
MW-21-165	Alluvial	6/28/07	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	20.5	23.06	(2.6)	NA	NA	156.0	-135.5	166.0	-145.5	168.0	-147.5
MW-22U	Alluvial	9/20/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	33.5	36.37	(2.9)	NA	NA	45.0	-11.5	55.0	-21.5	58.0	-24.5
MW-22-80	Alluvial	1/28/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	33.6	35.89	(2.3)	NA	NA	69.9	-36.3	79.9	-46.3	80.9	-47.3
MW-23-27	Surficial Fill	2/16/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	32.8	34.63	(1.9)	NA	NA	17.7	15.1	27.7	5.1	28.0	4.8
MW-23U	Alluvial	9/24/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	32.9	35.51	(2.6)	NA	NA	40.0	-7.1	50.0	-17.1	53.0	-20.1
MW-23-75	Alluvial	2/16/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	32.9	34.78	(1.9)	NA	NA	64.7	-31.8	74.7	-41.8	75.7	-42.8
MW-23-123	Alluvial	2/5/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	32.9	34.96	(2.1)	NA	NA	113.3	-80.4	123.3	-90.4	124.3	-91.4

Table 2
Well Construction Details

Well Number	Water-Bearing Zone	Date Installed	Date Decomm-issioned	Installation Method	Monument Type	Screen Type	Slot Size	Sand Pack	Well Diam.	Ground Surface	Top of Casing		Pump Inlet		Top Screen		Base Screen		Well Depth	
							(inches)	(Colorado)	(inches)	(feet COP)	(feet COP)	(feet bgs)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)
MW-24-70	Alluvial	2/3/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	31.4	33.74	(2.3)	NA	NA	60.1	-28.7	70.1	-38.7	71.1	-39.7
MW-24-130	Alluvial	2/2/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	31.3	33.66	(2.3)	NA	NA	120.1	-88.8	130.1	-98.8	131.1	-99.8
MW-25L	Alluvial	9/19/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.3	34.12	(2.8)	NA	NA	54.0	-22.7	64.0	-32.7	67.0	-35.7
MW-26U	Alluvial	9/25/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.4	33.93	(2.5)	NA	NA	38.5	-7.1	48.5	-17.1	51.7	-20.3
MW-27U	Alluvial	11/20/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.9	34.18	(2.3)	NA	NA	66.1	-34.2	76.1	-44.2	79.1	-47.2
MW-27L	Alluvial	11/16/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.9	34.16	(2.3)	NA	NA	106.0	-74.1	116.0	-84.1	119.0	-87.1
MW-28U	Alluvial	10/5/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	32.0	34.73	(2.7)	NA	NA	75.0	-43.0	85.0	-53.0	88.0	-56.0
MW-28L	Alluvial	10/4/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	32.4	34.87	(2.5)	NA	NA	109.8	-77.4	119.8	-87.4	122.8	-90.4
MW-29U	Alluvial	11/27/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	32.0	34.84	(2.8)	NA	NA	46.0	-14.0	56.0	-24.0	59.0	-27.0
MW-30U	Alluvial	11/14/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	27.4	30.46	(3.1)	NA	NA	40.1	-12.7	50.1	-22.7	53.1	-25.7
MW-31U	Alluvial	9/28/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	25.8	28.37	(2.6)	NA	NA	84.9	-59.1	94.9	-69.1	97.9	-72.1
MW-31L	Alluvial	9/27/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	26.0	28.53	(2.5)	NA	NA	105.0	-79.0	115.0	-89.0	118.0	-92.0
MW-32U	Alluvial	11/6/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	25.8	28.48	(2.7)	NA	NA	39.9	-14.1	49.9	-24.1	52.9	-27.1
MW-33U	Alluvial	11/5/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	24.8	27.66	(2.9)	NA	NA	38.0	-13.2	48.0	-23.2	51.0	-26.2
MW-34U	Alluvial	11/12/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	24.2	26.81	(2.6)	NA	NA	63.3	-39.1	73.3	-49.1	76.3	-52.1
MW-34L	Alluvial	11/8/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	24.1	26.91	(2.8)	NA	NA	99.0	-74.9	109.0	-84.9	112.0	-87.9
MW-35U	Alluvial	9/28/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	33.9	36.45	(2.6)	NA	NA	54.0	-20.1	64.0	-30.1	67.0	-33.1
MW-36U	Alluvial	9/27/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	35.1	37.93	(2.8)	NA	NA	44.0	-8.9	54.0	-18.9	57.0	-21.9
MW-37U	Alluvial	11/21/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	32.3	34.90	(2.6)	NA	NA	40.1	-7.8	50.1	-17.8	53.1	-20.8
MW-38U	Alluvial	11/28/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	2	31.8	34.74	(2.9)	NA	NA	50.1	-18.3	60.1	-28.3	63.1	-31.3
PW-1-80	Alluvial	8/9/05	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	10-20	6	32.0	34.07	(2.1)	NA	NA	39.5	-7.5	79.5	-47.5	82.0	-50.0
PW-3-85	Alluvial	6/20/07	-	Cable Tool	Above-grade	Continuous wrap stainless steel	0.035	10-20	8	25.2	26.72	(1.5)	NA	NA	75.0	-49.8	85.0	-59.8	95.0	-69.8
WS-11-125	Alluvial	3/10/03	-	Sonic	Flush	Continuous wrap stainless steel	0.010	10-20	2	33.3	33.06	0.2	NA	NA	109.0	-75.7	124.0	-90.7	125.0	-91.7
WS-11-161	Alluvial	3/10/03	-	Sonic	Flush	Continuous wrap stainless steel	0.010	10-20	2	33.3	33.06	0.2	NA	NA	145.0	-111.7	160.0	-126.7	161.0	-127.7
WS-12-125	Alluvial	9/21/03	-	Sonic	Flush	Continuous wrap stainless steel	0.010	10-20	2	34.5	34.01	0.5	NA	NA	109.0	-74.5	124.0	-89.5	125.0	-90.5
WS-12-161	Alluvial	9/21/03	-	Sonic	Flush	Continuous wrap stainless steel	0.010	10-20	2	34.5	34.02	0.5	NA	NA	145.0	-110.5	160.0	-125.5	161.0	-126.5
WS-14-125	Alluvial	7/9/04	-	Sonic	Flush	Continuous wrap stainless steel	0.010	10-20	2	33.8	33.30	0.5	NA	NA	109.0	-75.2	124.0	-90.2	125.0	-91.2
WS-14-161	Alluvial	7/9/04	-	Sonic	Flush	Continuous wrap stainless steel	0.010	10-20	2	33.8	33.37	0.4	NA	NA	145.0	-111.2	160.0	-126.2	161.0	-127.2
WS-21-112	Alluvial	6/13/06	-	Sonic	Flush	Slotted PVC	0.010	10-20	2	35.4	34.69	0.7	NA	NA	101.0	-65.6	111.0	-75.6	112.0	-76.6
WS-26-86	Alluvial	10/29/08	-	Sonic	Flush	NA	0.010	10-20	2	34.9	34.43	0.5	NA	NA	75.0	-40.1	85.0	-50.1	86.0	-51.1
Existing Observation Well																				
OW-1F	Surficial Fill	3/23/12	-	Sonic	Above-grade	Slotted PVC	0.010	10-20	2	35.3	37.60	(2.3)	NA	NA	30.0	5.3	35.0	0.3	35.3	0.0
OW-2F	Surficial Fill	3/22/12	-	Sonic	Above-grade	Slotted PVC	0.010	10-20	2	34.5	36.86	(2.4)	NA	NA	25.6	8.9	30.6	3.9	30.9	3.6
OW-5F	Surficial Fill	11/29/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	32.2	34.70	(2.5)	NA	NA	28.5	3.7	33.5	-1.3	33.8	-1.6
OW-7-17	Surficial Fill	2/23/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	24.2	26.42	(2.2)	NA	NA	12.5	11.7	17.5	6.7	17.7	6.5
OW-8-15	Surficial Fill	2/12/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	24.6	26.31	(1.8)	NA	NA	10.1	14.5	15.1	9.5	15.3	9.3
OW-8-28	Alluvial	8/13/10	-	Hollow-Stem Auger	Above-grade	Slotted PVC	0.020	10-20	2	23.8	26.27	(2.5)	NA	NA	23.1	0.7	28.1	-4.3	28.7	-4.9

Table 2
Well Construction Details

Well Number	Water-Bearing Zone	Date Installed	Date Decomm-issioned	Installation Method	Monument Type	Screen Type	Slot Size	Sand Pack	Well Diam.	Ground Surface	Top of Casing		Pump Inlet		Top Screen		Base Screen		Well Depth	
							(inches)	(Colorado)	(inches)	(feet COP)	(feet COP)	(feet bgs)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)
OW-9-25	Surficial Fill	3/8/10	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	33.1	35.29	(2.2)	NA	NA	20.0	13.1	25.0	8.1	25.3	7.8
OW-10F	Surficial Fill	9/20/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	30.8	33.75	(3.0)	NA	NA	20.7	10.1	25.7	5.1	26.0	4.8
Existing Extraction Well																				
PW-1U	Alluvial	1/9/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	35.0	37.50	(2.5)	52.0	-17.0	55.1	-20.1	70.1	-35.1	75.1	-40.1
PW-1L	Alluvial	1/8/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	34.9	37.32	(2.4)	109.6	-74.7	114.8	-79.9	134.8	-99.9	139.6	-104.7
PW-2U	Alluvial	4/25/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	34.5	36.70	(2.2)	55.8	-21.3	57.8	-23.3	72.8	-38.3	5.0	29.5
PW-2L	Alluvial	2/6/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	34.5	37.14	(2.6)	114.4	-79.9	120.1	-85.6	140.1	-105.6	145.1	-110.6
PW-2L-A ¹	Alluvial	12/12/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	34.2	36.70	(2.5)	NA	NA	119.8	-85.6	139.8	-105.6	144.8	-110.6
PW-3U	Alluvial	4/11/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	25.6	27.52	(1.9)	41.7	-16.1	42.8	-17.2	57.8	-32.2	62.8	-37.2
PW-3-118	Alluvial	6/13/07	-	Cable Tool	Above-grade	Continuous wrap stainless steel	0.035	10-20	8	25.5	27.01	(1.5)	104.5	-79.0	108.0	-82.5	118.0	-92.5	128.0	-102.5
PW-4U	Alluvial	1/16/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	28.3	31.01	(2.7)	43.8	-15.5	47.2	-18.9	62.2	-33.9	67.2	-38.9
PW-4L	Alluvial	1/10/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	28.2	30.27	(2.1)	97.4	-69.2	105.4	-77.2	125.4	-97.2	130.4	-102.2
PW-5U	Alluvial	4/20/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	32.5	34.82	(2.3)	47.7	-15.2	49.9	-17.4	64.9	-32.4	69.9	-37.4
PW-5L	Alluvial	1/23/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	32.3	34.19	(1.9)	100.6	-68.3	105.7	-73.4	125.7	-93.4	130.7	-98.4
PW-6U	Alluvial	4/17/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	31.5	33.93	(2.4)	48.6	-17.1	49.4	-17.9	64.4	-32.9	69.4	-37.9
PW-6L	Alluvial	11/6/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	31.0	33.32	(2.3)	97.7	-66.7	103.7	-72.7	123.7	-92.7	128.7	-97.7
PW-7-93	Alluvial	2/22/10	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	8	24.2	26.81	(2.6)	67.4	-43.2	73.5	-49.3	93.5	-69.3	95.5	-71.3
PW-8-39	Alluvial	8/13/10	-	Hollow-Stem Auger	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	23.2	25.75	(2.5)	21.5	1.7	24.2	-1.0	39.2	-16.0	42.2	-19.0
PW-8-68	Alluvial	2/11/10	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	8	24.6	27.18	(2.5)	43.0	-18.4	48.0	-23.4	68.0	-43.4	70.0	-45.4
PW-9-92	Alluvial	3/1/10	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	8	33.0	35.84	(2.8)	67.7	-34.7	72.6	-39.6	92.6	-59.6	94.6	-61.6
PW-10L	Alluvial	11/12/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	10-20	6	31.5	33.40	(1.9)	58.1	-26.6	59.8	-28.3	79.8	-48.3	84.8	-53.3
PW-10-LA ¹	Alluvial	10/12/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.035	16-30	6	31.4	33.20	(1.8)	NA	NA	60.2	-28.8	80.2	-48.8	85.2	-53.8
PW-11U	Alluvial	1/26/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	24.0	26.78	(2.7)	NA	NA	49.8	-25.8	64.8	-40.8	69.8	-45.8
PW-12U	Alluvial	12/21/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	26.2	28.58	(2.4)	NA	NA	47.8	-21.6	62.8	-36.6	67.8	-41.6
PW-13U	Alluvial	12/28/12	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	32.2	34.60	(2.4)	NA	NA	57.6	-25.4	72.6	-40.4	77.6	-45.4
PW-14U	Alluvial	1/14/13	-	Sonic	Above-grade	Continuous wrap stainless steel	0.020	16-30	6	31.9	34.68	(2.7)	NA	NA	57.8	-25.9	67.8	-35.9	72.8	-40.9
Existing Piezometers																				
PZ1-5	Alluvial	3/17/05	-	Manual	Above-grade	Solinst push point	NA	NA	1	10.0	35.98	(26.0)	NA	NA	4.5	5.5	5.4	4.6	5.6	4.3
PZ1-20	Alluvial	3/17/05	-	Manual	Above-grade	Solinst push point	NA	NA	1	10.2	36.34	(26.2)	NA	NA	19.3	-9.2	20.2	-10.1	20.5	-10.3
PZ1-50	Alluvial	11/23/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.2	37.58	(27.4)	NA	NA	45.1	-34.9	50.1	-39.9	50.4	-40.2
PZ2-5	Alluvial	3/18/05	-	Manual	Above-grade	Solinst push point	NA	NA	1	2.9	37.83	(34.9)	NA	NA	5.5	-2.6	6.4	-3.5	6.7	-3.8
PZ2-20	Alluvial	3/17/05	-	Manual	Above-grade	Solinst push point	NA	NA	1	3.4	37.81	(34.4)	NA	NA	20.6	-17.2	21.5	-18.1	21.7	-18.4
PZ2-43	Alluvial	12/3/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	3.8	37.87	(34.1)	NA	NA	38.3	-34.5	43.3	-39.5	43.6	-39.8
PZ2-77	Alluvial	12/2/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	3.1	38.55	(35.5)	NA	NA	71.9	-68.9	76.9	-73.9	77.2	-74.2
PZ4-12	Alluvial	12/4/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	-8.6	34.59	(43.2)	NA	NA	6.7	-15.3	11.7	-20.3	12.0	-20.6
PZ4-41	Alluvial	11/24/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	-8.3	34.48	(42.8)	NA	NA	36.1	-44.4	41.1	-49.4	41.4	-49.7
PZ5-5	Alluvial	11/20/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.7	16.46	(5.7)	NA	NA	3.8	6.9	4.8	5.9	5.0	5.7

Table 2
Well Construction Details

Well Number	Water-Bearing Zone	Date Installed	Date Decomm-issioned	Installation Method	Monument Type	Screen Type	Slot Size	Sand Pack	Well Diam.	Ground Surface	Top of Casing		Pump Inlet		Top Screen		Base Screen		Well Depth	
							(inches)	(Colorado)	(inches)	(feet COP)	(feet COP)	(feet bgs)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)	(feet bgs)	(feet COP)
PZ5-20	Alluvial	11/20/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.8	16.20	(5.4)	NA	NA	15.0	-4.2	20.0	-9.2	20.3	-9.5
PZ5-55	Alluvial	11/20/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.9	16.25	(5.4)	NA	NA	50.0	-39.1	55.0	-44.1	55.3	-44.4
PZ5-85	Alluvial	11/19/09	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.9	16.38	(5.5)	NA	NA	79.9	-69.0	84.9	-74.0	85.2	-74.3
PZ6-5	Alluvial	10/17/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	7.8	14.72	(6.9)	NA	NA	3.9	3.9	4.9	2.9	5.0	2.8
PZ6-50	Alluvial	10/17/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	8.1	14.88	(6.8)	NA	NA	45.2	-37.1	50.2	-42.1	50.5	-42.4
PZ6-115	Alluvial	10/18/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	7.4	13.79	(6.3)	NA	NA	110.1	-102.7	115.1	-107.7	115.4	-108.0
PZ6-150	Alluvial	10/26/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	7.7	14.15	(6.4)	NA	NA	145.4	-137.7	150.4	-142.7	150.7	-143.0
PZ7-5	Alluvial	10/22/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.6	16.36	(5.8)	NA	NA	4.1	6.5	5.2	5.4	5.3	5.3
PZ7-50	Alluvial	10/19/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.7	16.40	(5.7)	NA	NA	43.2	-32.5	48.2	-37.5	48.5	-37.8
PZ7-100	Alluvial	10/23/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	9.9	16.13	(6.2)	NA	NA	94.3	-84.4	99.3	-89.4	99.6	-89.7
PZ7-150	Alluvial	10/31/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	10.0	15.50	(5.5)	NA	NA	145.3	-135.3	150.3	-140.3	150.6	-140.6
PZ8-5	Alluvial	10/9/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	6.8	12.21	(5.4)	NA	NA	4.5	2.3	5.4	1.4	5.5	1.3
PZ8-50	Alluvial	10/9/12	-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	6.9	12.45	(5.5)	NA	NA	44.7	-37.8	49.7	-42.8	50.0	-43.1
Stilling Well Up	Willamette River	5/23/13	-	Manual	NA	NA	NA	NA	2	-8.6	34.41	(43.0)	NA	NA	NA	NA	NA	NA	NA	NA
Stilling Well Down	Willamette River	5/23/13	-	Manual	NA	NA	NA	NA	2	-8.6	34.39	(43.0)	NA	NA	NA	NA	NA	NA	NA	NA
Proposed Piezometers																				
PZ9-5	Alluvial		-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	9.0	15.00	(6.0)	NA	NA	4.0	5.0	5.0	4.0	5.5	3.5
PZ9-50	Alluvial		-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	9.0	15.00	(6.0)	NA	NA	45.0	-36.0	50.0	-41.0	50.5	-41.5
PZ9-75	Alluvial		-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	9.0	15.00	(6.0)	NA	NA	69.0	-60.0	74.0	-65.0	74.5	-65.5
PZ9-110	Alluvial		-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	9.0	15.00	(6.0)	NA	NA	105.0	-96.0	110.0	-101.0	110.5	-101.5
PZ9-150	Alluvial		-	Sonic	Above-grade	Slotted PVC	0.020	10-20	2	9.0	15.00	(6.0)	NA	NA	145.0	-136.0	150.0	-141.0	150.5	-141.5
Decommissioned Wells																				
PZ-PW2	Alluvial	3/21/12	9/25/12	Sonic	Above-grade	Slotted PVC	0.010	10-20	2	34.4	37.11	(2.8)	NA	NA	63.8	-29.4	68.8	-34.4	69.1	-34.7
PZ-PW3	Alluvial	3/19/12	9/24/12	Sonic	Above-grade	Slotted PVC	0.010	10-20	2	25.3	27.41	(2.1)	NA	NA	50.3	-25.0	55.3	-30.0	55.6	-30.3
MW-17-79	Alluvial	7/26/05	9/28/12	Sonic	Above-grade	Continuous wrap stainless steel	0.010	10-20	2	32.6	34.83	(2.3)	NA	NA	38.5	-5.9	78.5	-45.9	80.5	-47.9
MW-16-125	Alluvial	7/15/04	4/26/10	Sonic	Above-grade	Slotted stainless steel	0.010	10-20	2	30.5	33.18	(2.7)	NA	NA	115.0	-84.5	125.0	-94.5	127.5	-97.0

Notes:
1 = to be abandoned
bgs = below ground surface
btc = below top of casing
COP = City of Portland Datum
NA = not applicable
nd = no data
ns = not surveyed
PVC = polyvinyl chloride

Table 3
Source Control Monitoring Plan

Well ID	Water-Bearing Zone	Estimated Relative Efficiency	Data Collection Objectives	Monitoring Water Level Transducer ⁶	Controlling Water Level Transducer	Extraction Wells associated with each Control Well	Transducer Connected to Logic and Logging System	Sampling Program ¹	Source Control Sampling Program		
								Semi-Annual	Tiered ²	Semi-Annual ¹	DNAPL Monitoring ⁵
Shoreline Monitoring Wells											
MW-1-22	Surficial Fill	M	A, F					X		X	
MW-1-55	Alluvial	L	B, F	X				X		X	
MW-1-82	Alluvial	H	C, F	X				X		X	
MW-2-32	Surficial Fill	M	A, F					X		X	
MW-2-61	Alluvial	L	B, F					X		X	
MW-2-104	Alluvial	H	C, F					X		X	
MW-3-26	Surficial Fill	M	A, F					X		X	X
MW-3-56	Alluvial	L	B, F					X		X	X
MW-4-35	Surficial Fill	M	A, F					X		X	X
MW-4-57	Alluvial	L	B	X				X		X	X
MW-4-101	Alluvial	H	C, F					X		X	X
MW-5-32	Alluvial	L	B, F	X				X		X	X
MW-5-100	Alluvial	H	B, F					X		X	X
MW-5-175	Alluvial	H	C, F	X				X		X	X
MW-16-45	Alluvial	L	B					NS		NS	X
MW-16-65	Alluvial	L	B, F					X		X	X
MW-18-30	Surficial Fill	M	A	X				NS		NS	X
MW-18-125	Alluvial	H	C, F					X		X	X
MW-18-180	Alluvial	H	D, F	X				X		X	X
MW-19-22	Surficial Fill	M	A, F	X				X		X	X
MW-19-125	Alluvial	H	C, F					X		X	X
MW-19-180	Alluvial	H	D, F	X				X		X	X
MW-20-120	Alluvial	H	C, F					X		X	X
MW-21-12	Surficial Fill	M	A, F					X		X	
MW-21U	Alluvial	L	B, F	X				NS		X ³	
MW-21-75	Alluvial	H	C		X	PW-8-68	X	X		NS ⁴	
MW-21-115	Alluvial	H	C, F					X		X	
MW-21-165	Alluvial	H	D, F	X				X		X	
MW-22U	Alluvial	L	B, F	X				NS		X ³	
MW-22-80	Alluvial	H	C		X	PW-10L	X	NS		NS ⁴	
MW-23-27	Surficial Fill	M	A, F					NS		X ³	
MW-23U	Alluvial	L	B, F	X				NS		X ³	
MW-23-75	Alluvial	L	C		X	PW-9-92	X	NS		NS ⁴	
MW-23-123	Alluvial	H	C, F					NS		X ³	
MW-24-70	Alluvial	L	B					NS		X ³	X
MW-24-130	Alluvial	H	C		X	PW-7-93	X	NS		NS ⁴	X
MW-25L	Alluvial	H	C		X		X	NS		X ³	

Table 3
Source Control Monitoring Plan

Well ID	Water-Bearing Zone	Estimated Relative Efficiency	Data Collection Objectives	Monitoring Water Level Transducer ⁶	Controlling Water Level Transducer	Extraction Wells associated with each Control Well	Transducer Connected to Logic and Logging System	Sampling Program ¹	Source Control Sampling Program		
								Semi-Annual	Tiered ²	Semi-Annual ¹	DNAPL Monitoring ⁵
MW-26U	Alluvial	L	B		X	PW-6U	X	NS		NS ⁴	X
MW-27L	Alluvial	H	C		X	PW-6L	X	NS		NS ⁴	X
MW-27U	Alluvial	L	B, F	X				NS		X ³	X
MW-28L	Alluvial	H	C		X	PW-5-L	X	NS		NS ⁴	X
MW-28U	Alluvial	L	B, F	X				NS		X ³	X
MW-29U	Alluvial	L	B		X	PW-13U	X	NS		NS ⁴	X
MW-30U	Alluvial	L	B		X	PW-4U	X	NS		NS ⁴	X
MW-31L	Alluvial	H	C		X	PW-4L	X	NS		NS ⁴	X
MW-31U	Alluvial	L	B, F	X				NS		X ³	X
MW-32U	Alluvial	L	B		X	PW-12U	X	NS		NS ⁴	X
MW-33U	Alluvial	L	B		X	PW-3U	X	NS		NS ⁴	X
MW-34L	Alluvial	H	C		X	PW-3-118	X	NS		NS ⁴	X
MW-34U	Alluvial	L	B, F	X				NS		X ³	X
MW-35U	Alluvial	L	B		X	PW-11U	X	NS		NS ⁴	X
MW-36U	Alluvial	L	B		X	PW-2U	X	NS		NS ⁴	X
MW-37U	Alluvial	L	B		X	PW-14U	X	NS		NS ⁴	X
MW-38U	Alluvial	L	B		X	PW-5U	X	NS		NS ⁴	X
PW-01-80	Alluvial	L	B					NS		NS	X
PW-3-85	Alluvial	L	B, F	X				NS		X	X
Shoreline Monitoring Well Total				18	18		18	25	0	36	38
Monitored Siltronic Wells											
WS-8-33	Surficial Fill	M	A	X				X		NS	
WS-8-59	Alluvial	L	B	X				X		NS	
WS-11-161	Alluvial	H	D, F	X				X		X	X
WS-12-125	Alluvial	H	D, F		X	PW-1L	X	X		NS ⁴	
WS-12-161	Alluvial	H	D	X				X		NS	
WS-14-161	Alluvial	H	D, F	X				X		X	X
WS-21-112	Alluvial	H	C		X	PW-2L	X	X		NS ⁴	X
WS-26-86	Alluvial	L	B, F		X	PW-1U	X	X		NS ⁴	
Monitored Siltronic Well Total				5	3		3	8	0	2	3

Table 3
Source Control Monitoring Plan

Well ID	Water-Bearing Zone	Estimated Relative Efficiency	Data Collection Objectives	Monitoring Water Level Transducer ⁶	Controlling Water Level Transducer	Extraction Wells associated with each Control Well	Transducer Connected to Logic and Logging System	Sampling Program ¹	Source Control Sampling Program		
								Semi-Annual	Tiered ²	Semi-Annual ¹	DNAPL Monitoring ⁵
Observation Wells											
OW-1F	Surficial Fill	M	A, F	X				NS		X ³	
OW-2F	Surficial Fill	M	A, F	X				NS		X ³	X
OW-5F	Surficial Fill	M	A, F	X				NS		X ³	X
OW-7-17	Surficial Fill	M	A, F	X				NS		X ³	
OW-8-15	Surficial Fill	M	A, F	X				NS		X ³	
OW-8-28	Alluvial	M	B, F					NS		X ³	
OW-9-25	Surficial Fill	M	A, F	X				NS		X ³	
OW-10F	Surficial Fill	M	A, F	X				NS		X ³	
Observation Well Total				7	0		0	0	0	8	2
Extraction Wells											
PW-1L	Alluvial	H	C, F	X ⁷			X	NS	X		
PW-1U	Alluvial	L	B, F	X			X	NS	X		
PW-2L	Alluvial	H	C, F	X ⁷			X	NS	X		X
PW-2U	Alluvial	L	B, F	X			X	NS	X		X
PW-3-118	Alluvial	H	C, F	X ⁷			X	NS	X		X
PW-3U	Alluvial	L	B, F	X			X	NS	X		X
PW-4L	Alluvial	H	C, F	X ⁷			X	NS	X		X
PW-4U	Alluvial	L	B, F	X			X	NS	X		X
PW-5L	Alluvial	H	C, F	X ⁷			X	NS	X		X
PW-5U	Alluvial	L	B, F	X			X	NS	X		X
PW-6L	Alluvial	H	C, F	X ⁷			X	NS	X		X
PW-6U	Alluvial	L	B, F	X			X	NS	X		X
PW-7-93	Alluvial	H	C, F	X ⁷			X	NS	X		
PW-8-39	Alluvial	H	B, F	X			X	NS	X		
PW-8-68	Alluvial	H	C, F	X			X	NS	X		
PW-9-92	Alluvial	H	C, F	X ⁷			X	NS	X		
PW-10L	Alluvial	H	C, F	X ⁷			X	NS	X		
PW-11U	Alluvial	L	B, F	X			X	NS	X		X
PW-12U	Alluvial	L	B, F	X			X	NS	X		X
PW-13U	Alluvial	L	B, F	X			X	NS	X		X
PW-14U	Alluvial	L	B, F	X			X	NS	X		X
Extraction Well Total				21	0		21	0	21	0	14

Table 3
Source Control Monitoring Plan

Well ID	Water-Bearing Zone	Estimated Relative Efficiency	Data Collection Objectives	Monitoring Water Level Transducer ⁶	Controlling Water Level Transducer	Extraction Wells associated with each Control Well	Transducer Connected to Logic and Logging System	Sampling Program ¹	Source Control Sampling Program		
								Semi-Annual	Tiered ²	Semi-Annual ¹	DNAPL Monitoring ⁵
Piezometers											
PZ1-5	Surficial Fill	M	A,E	X			X	NS		NS	
PZ1-20	Alluvial	L	B,E	X			X	NS		NS	
PZ1-50	Alluvial	H	C,E	X			X	NS		NS	
PZ2-5	Surficial Fill	M	A,E	X ⁸			X	NS		NS	
PZ2-20	Alluvial	L	B,E	X ⁸			X	NS		NS	
PZ2-43	Alluvial	H	C,E	X ⁸			X	NS		NS	
PZ2-77	Alluvial	H	C,E	X ⁸			X	NS		NS	
PZ4-12	Alluvial	L	A,E	X			X	NS		NS	
PZ4-41	Alluvial	H	B,E	X			X	NS		NS	
PZ5-5	Surficial Fill	M	A,E,F	X				NS		X ³	
PZ5-20	Alluvial	L	B,E,F	X				NS		X ³	
PZ5-55	Alluvial	H	C,E,F	X				NS		X ³	
PZ5-85	Alluvial	H	C,E,F	X				NS		X ³	
PZ6-5	Surficial Fill	M	A,E,F	X				NS		X ³	X
PZ6-50	Alluvial	L	B,E,F	X				NS		X ³	X
PZ6-115	Alluvial	H	C,E,F	X				NS		X ³	X
PZ6-150	Alluvial	H	D,E,F	X				NS		X ³	X
PZ7-5	Surficial Fill	M	A,E,F	X ⁸				NS		X ³	X
PZ7-50	Alluvial	L	B,E,F	X ⁸				NS		X ³	X
PZ7-100	Alluvial	H	C,E,F	X ⁸				NS		X ³	X
PZ7-150	Alluvial	H	D,E,F	X				NS		X ³	X
PZ8-5	Surficial Fill	M	A,E,F	X ⁸				NS		X ³	
PZ8-50	Alluvial	H	B,E,F	X ⁸				NS		X ³	
Piezometer Total				23	0		9	0	0	14	8
Proposed Piezometers											
PZ9-5	Surficial Fill	M	A,E,F	X ⁸				NS		X ³	X
PZ9-50	Alluvial	L	B,E,F	X ⁸				NS		X ³	X
PZ9-75	Alluvial	L	C,E,F	X ⁸				NS		X ³	X
PZ9-110	Alluvial	H	C,E,F	X				NS		X ³	X
PZ9-150	Alluvial	H	D,E,F	X				NS		X ³	X
Proposed Piezometer Total				5	0		0	0	0	5	5
Total (all wells and piezometers)				79	21		51	33	21	65	70

Table 3

Source Control Monitoring Plan

Notes:

NS = not sampled

A = Used to monitor groundwater elevation and evaluate extent of groundwater capture in the surficial fill.

B = Used to monitor groundwater elevation and evaluate extent of groundwater capture in the Upper Alluvium.

C = Used to monitor groundwater elevation and evaluate extent of groundwater capture in the Lower Alluvium.

D = Used to monitor groundwater elevation and evaluate extent of groundwater capture in the Lower Alluvium below the aquitard.

E = Shoreline and/or offshore piezometer to monitor groundwater elevation and extent of groundwater capture in nearshore river sediments.

F = Will be used to monitor changes in groundwater quality parameters and chemistry over time during HC&C system operation.

L = Estimated to have low hydraulic efficiency (typically screened in Upper Alluvium). Designation may change based on the results of Phase 1 testing.

H = Estimated to have high hydraulic efficiency (typically screened in Lower Alluvium). Designation may change based on the results of Phase 1 testing.

M = estimated to have minimal hydraulic efficiency (typically screened in fill). Designation may change based on the results of Phase 1 testing.

1 = During the first year of testing, the two semi-annual sampling events will occur within 6 months of the start of Phase 1 testing. Wells with measurable DNAPL will not be sampled.

2 = Tiered Monitoring Program entails monthly sampling for 1 year beginning with Phase 2 testing.

3 = Newly constructed wells, with the exception of control wells, will be sampled for four consecutive quarters, including the semi-annual sampling events.

4 = Control wells cannot be sampled without disruption to the pumping of the associated pumping well it controls. Newly installed wells will be initially sampled following well installation and development.

5 = Wells will be gaged for DNAPL daily at startup of Phase 1 pumping for 1 week, weekly for the next 3 weeks, every other week for the remainder of the first quarter, monthly until the completion of 1 year, and then following the monitoring program discussed above. At the completion of the first Phase 1 test, a plan will be developed for the remainder of Phase 1 testing, and this plan may be modified. Control wells will not be gaged while the system is operating in level control.

6 = Unless otherwise indicated, a 30 PSI LevelTroll 500 series transducer will be installed.

7 = 100 PSI LevelTroll 500 series transducer will be installed.

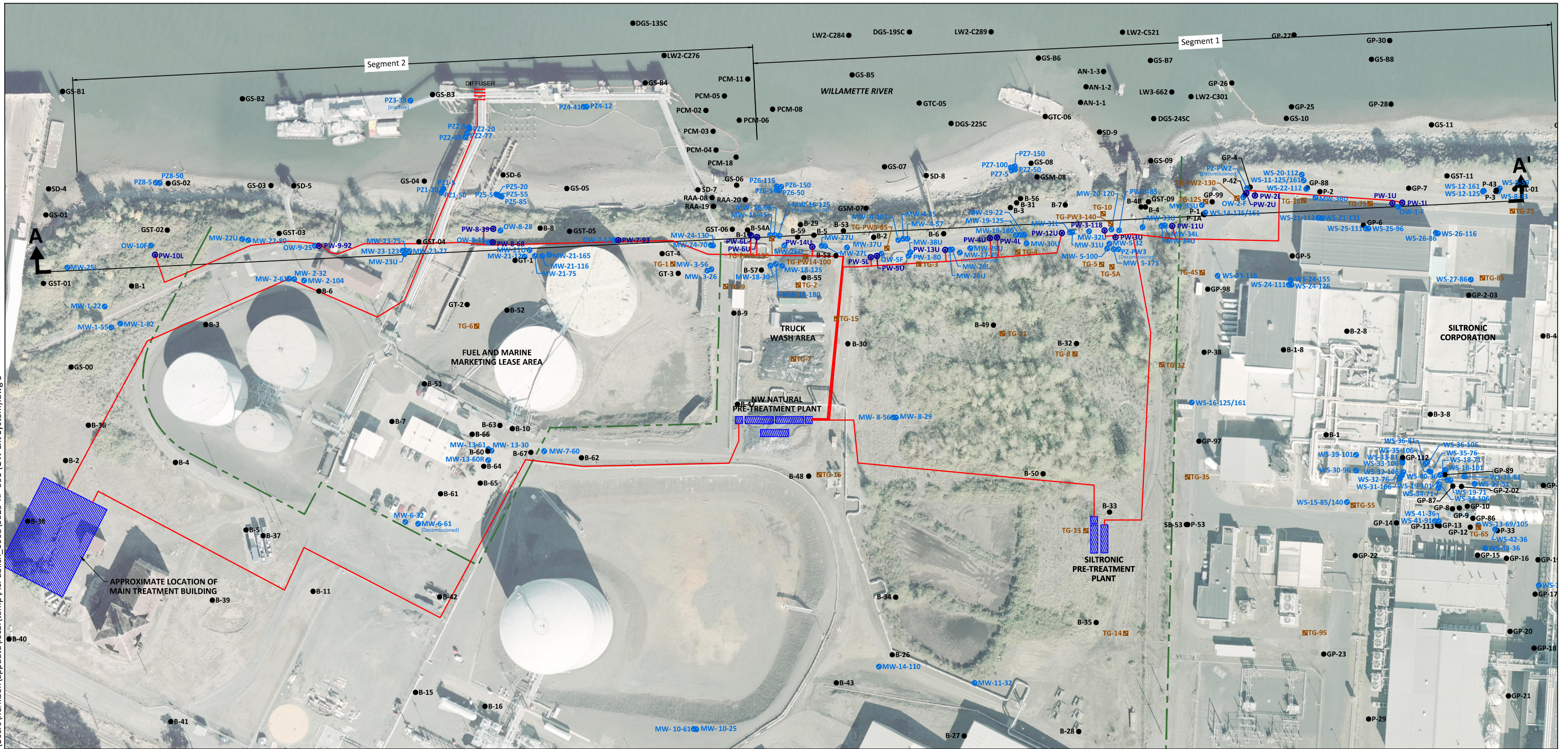
8 = AquaTroll series transducer will be installed that will additionally monitor temperature and specific conductance.

DNAPL = dense nonaqueous phase liquid

HC&C = hydraulic control and containment

FIGURES

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Aug 01, 2013 9:52am heriksen



LEGEND:

- MW-2-32** Existing Monitoring Well, Observation Well, or Piezometer
- PW-8-39** Existing Extraction Well
(U = Upper Alluvium, L = Lower Alluvium)

- TG-6** TarGOST Boring
- GTC-05** Sediment Sample or Soil Boring
- Source Control Main Pipeline Route

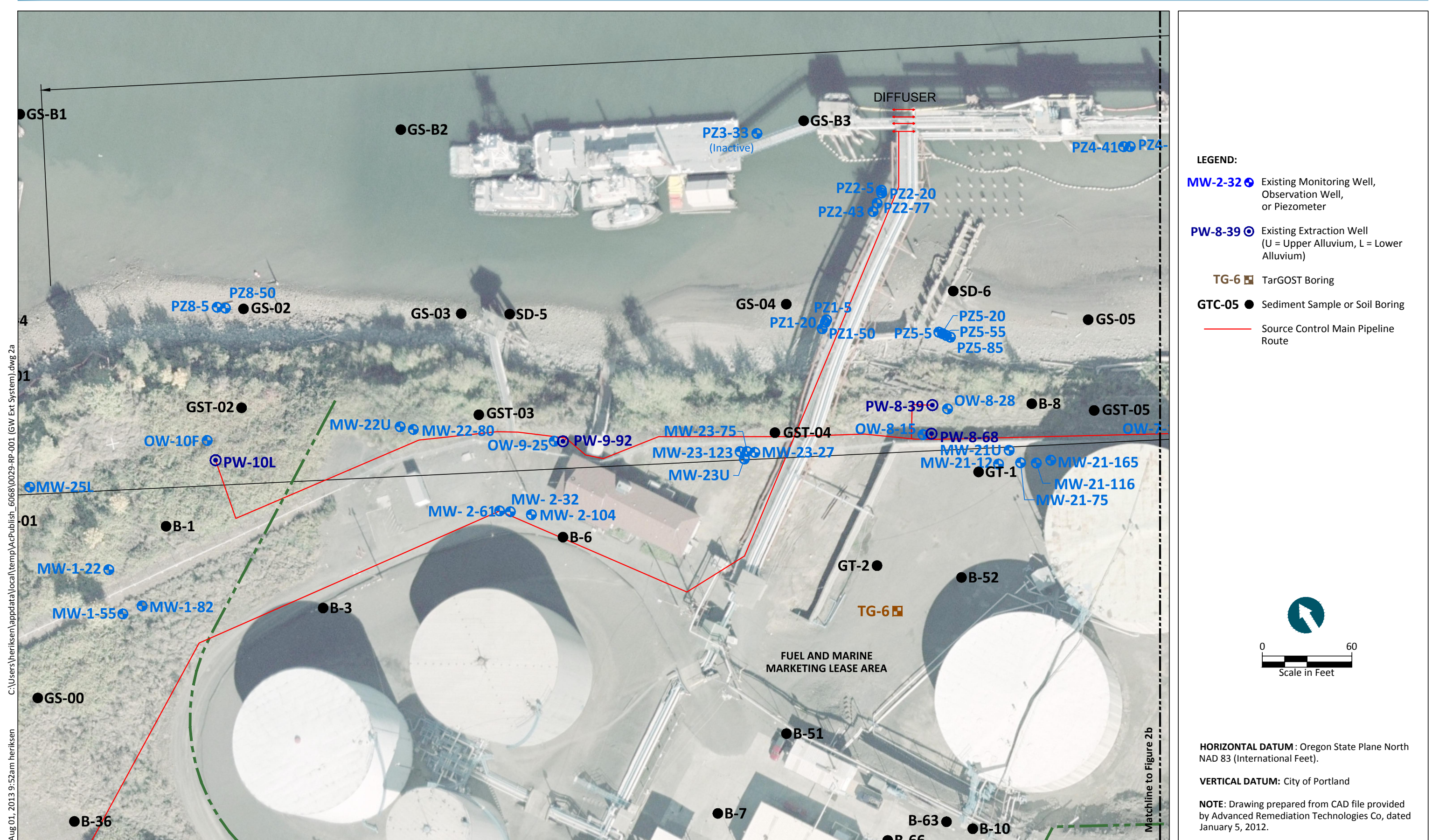
HORIZONTAL DATUM: Oregon State Plane North
NAD 83 (International Feet).

VERTICAL DATUM: City of Portland

NOTE: Drawing prepared from CAD file provided
by Advanced Remediation Technologies Co, dated
January 5, 2012.



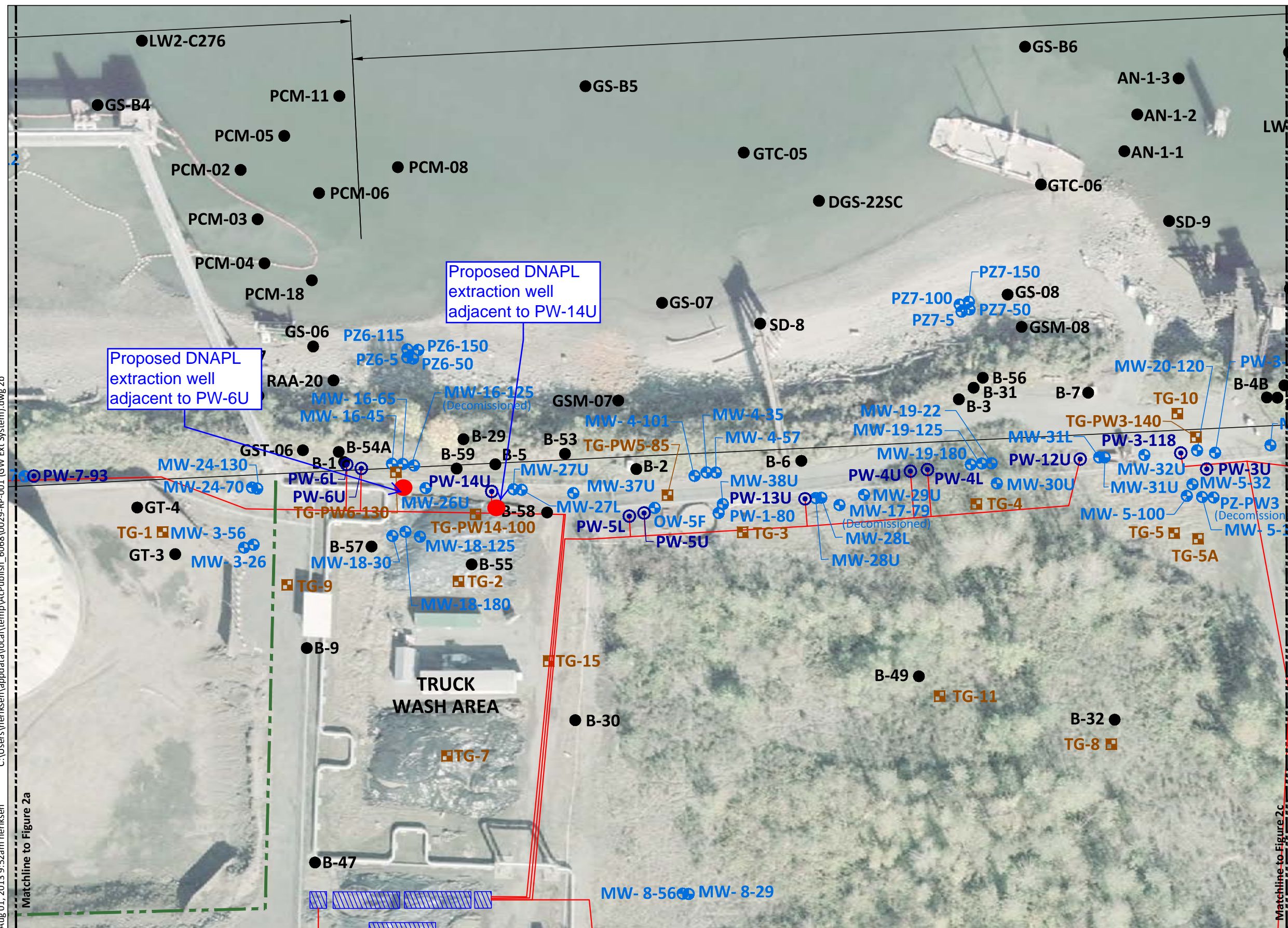
Figure 1
General Well Location Map
Groundwater Source Control Extraction System Test Plan
NW Natural Gasco Site



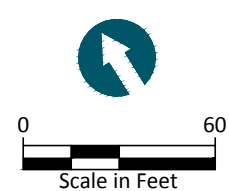
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Figure 2a
 Map of Groundwater Extraction and Treatment System
 Groundwater Source Control Extraction System Test Plan
 NW Natural Gasco Site

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- LEGEND:**
- MW-2-32** Existing Monitoring Well, Observation Well, or Piezometer
 - PW-8-39** Existing Extraction Well (U = Upper Alluvium, L = Lower Alluvium)
 - TG-6** TarGOST Boring
 - GTC-05** Sediment Sample or Soil Boring
 - Source Control Main Pipeline Route



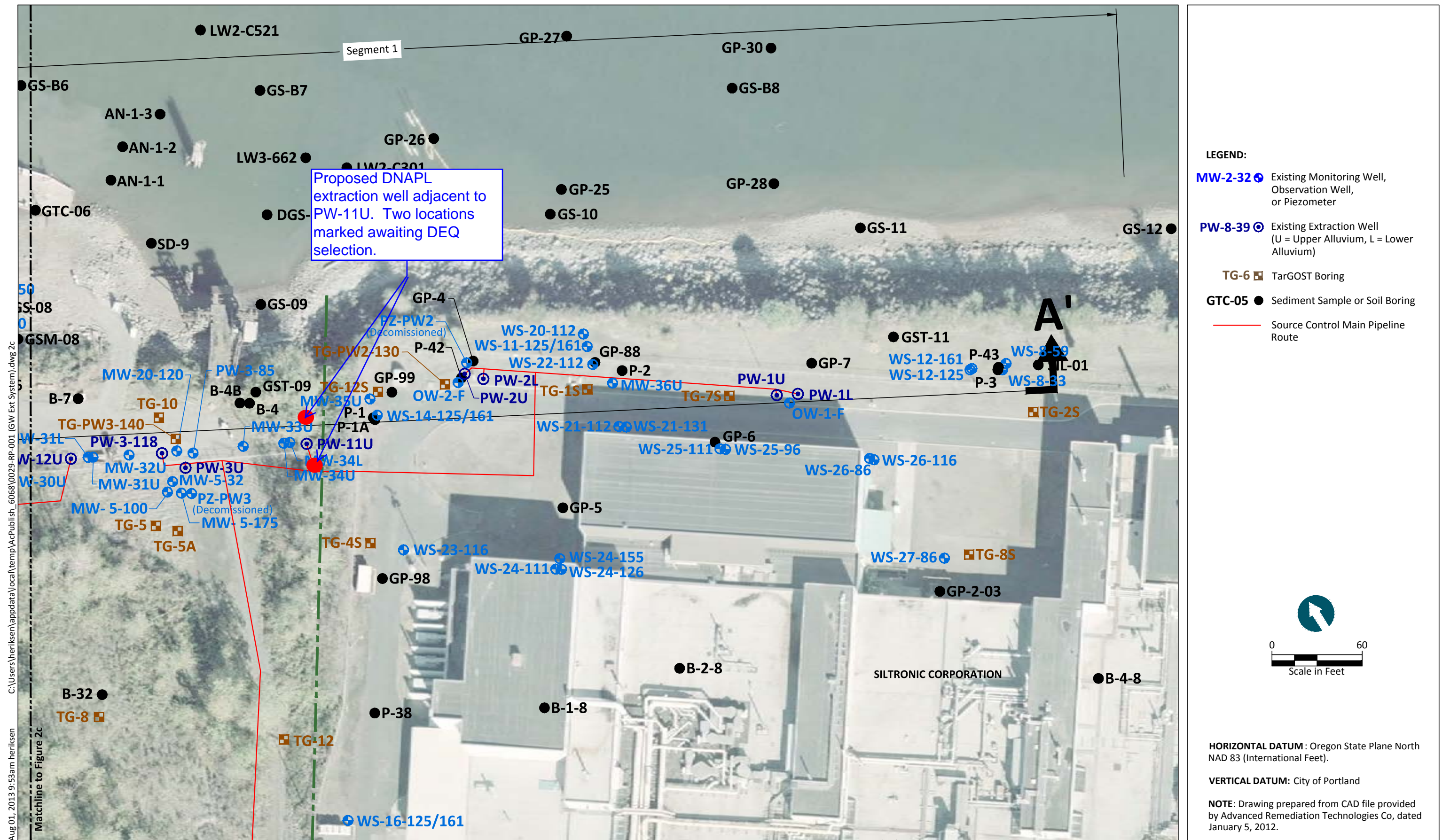
HORIZONTAL DATUM: Oregon State Plane North NAD 83 (International Feet).

VERTICAL DATUM: City of Portland

NOTE: Drawing prepared from CAD file provided by Advanced Remediation Technologies Co, dated January 5, 2012.



Figure 2b
Map of Groundwater Extraction and Treatment System
Groundwater Source Control Extraction System Test Plan
NW Natural Gasco Site

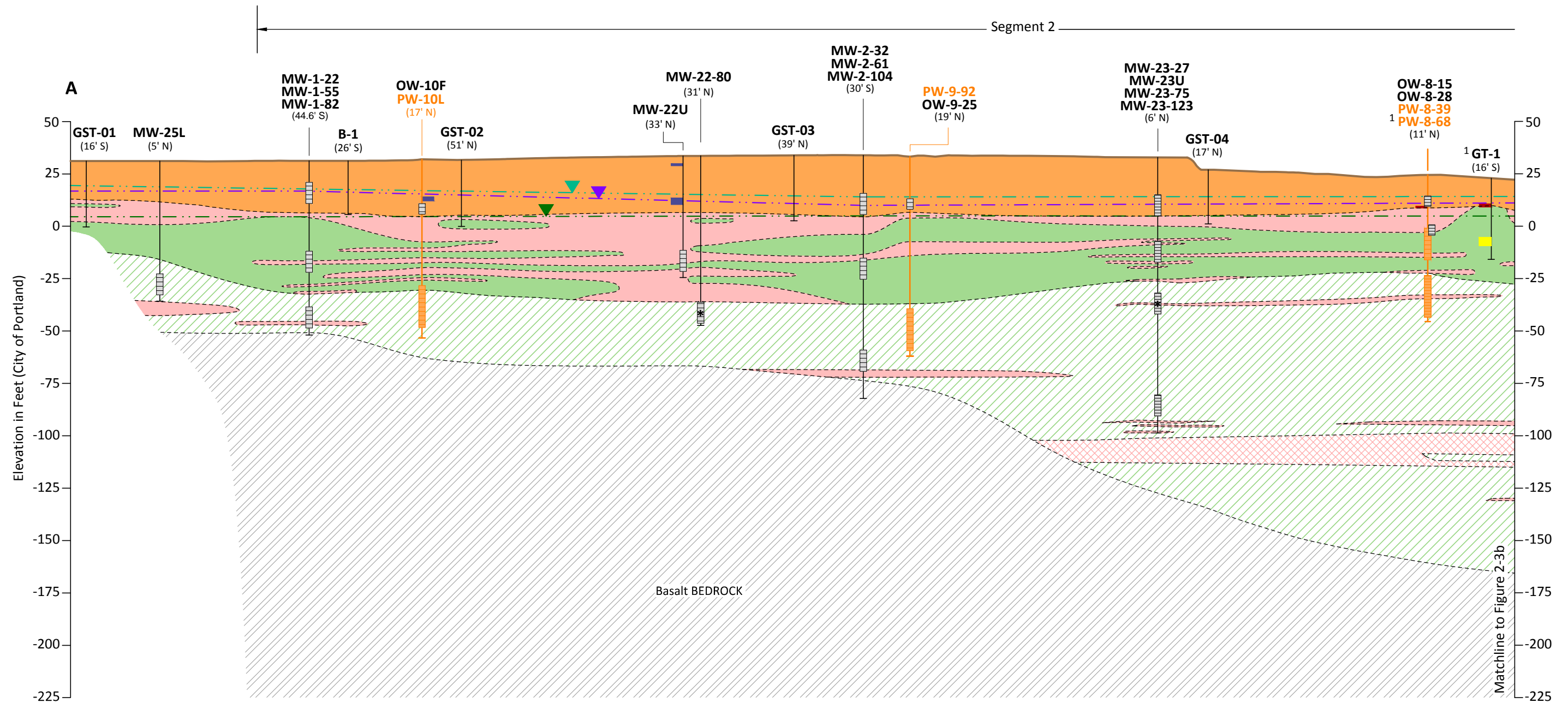


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Matchline to Figure 2c

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LEGEND:

- Fill WBZ** - Fill composed of gravel, silt, sand, metal, brick, and concrete debris
- Upper Alluvium WBZ** - Primarily fine to medium grained SAND and SILTY-SAND interbedded with thin silt and sandy-silt layers
- Lower Alluvium WBZ** - Primarily medium grained SAND with generally less than 5% fines.

- Aquitard** - Primarily SILT and SANDY-SILT interbedded with thin sand and silty-sand layers
- Primarily SILT and SANDY-SILT interbedded with thin sand and silty-sand layers
- Alluvial GRAVEL, sandy gravel, gravelly sand, and gravelly silt
- Basalt BEDROCK

- Potentiometric Surface of Surficial Fill (measured June 3, 2009)
- Potentiometric Surface of Surficial Fill (measured August 5, 2009)
- Potentiometric Surface of Alluvium (measured August 5, 2009)
- Existing Ground Surface

MW-21-16 (57' E)

- Boring ID
- Offset Distance in Feet

- Tar Interval
- Oil or Mixed Oil and Tar Interval
- Sheen Interval
- Well Screen
- * — Control Well

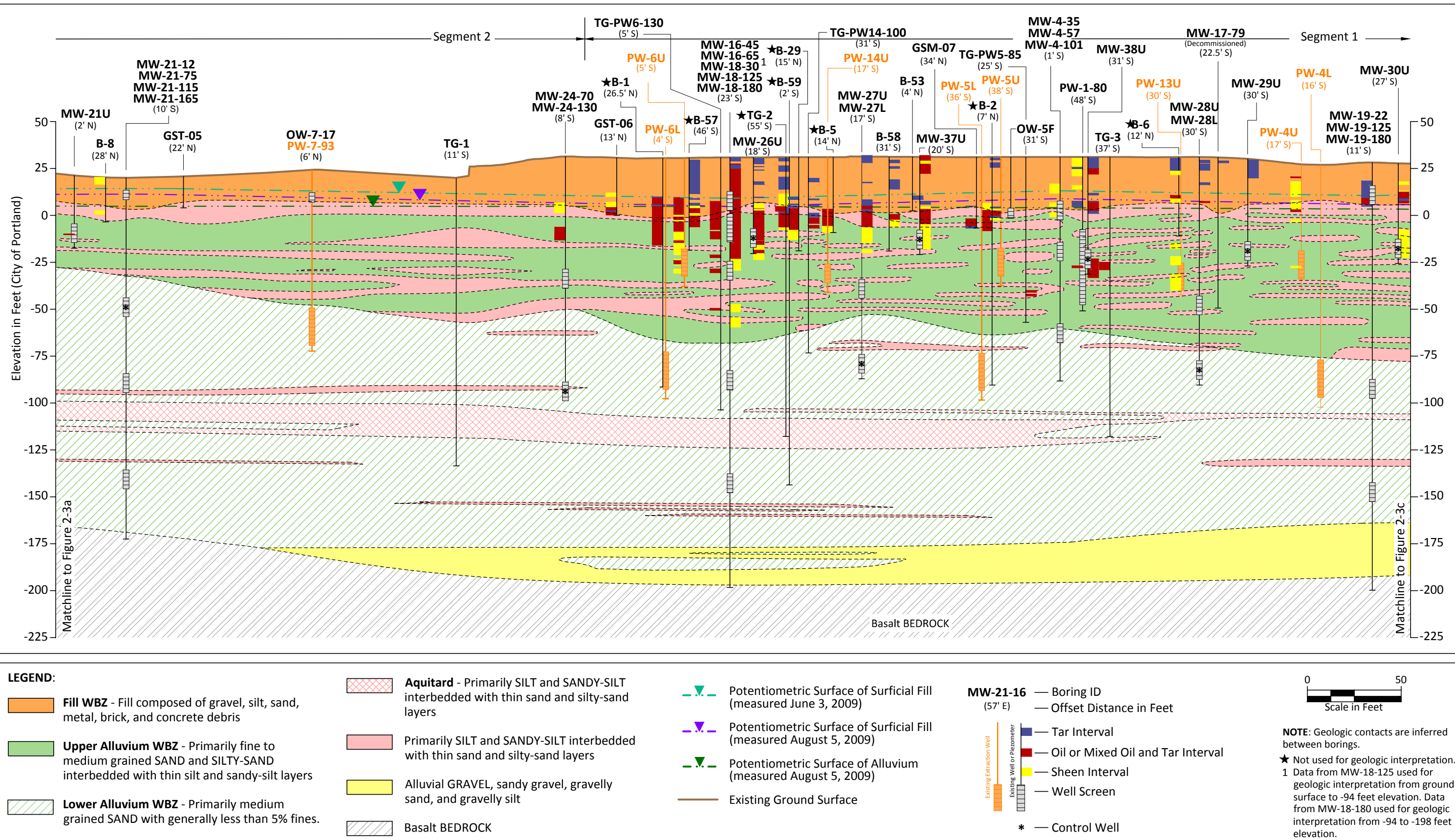


NOTE: Geologic contacts are inferred between borings.
¹ Based on visual observations and analytical testing conducted by Hahn and Associates (Remedial Investigation Report, Hahn and Associates, April 2007), the oil and sheen detected in the fill unit does not appear to be MGP-related, but appears to be associated with petroleum products stored in the FAMM storage tanks.

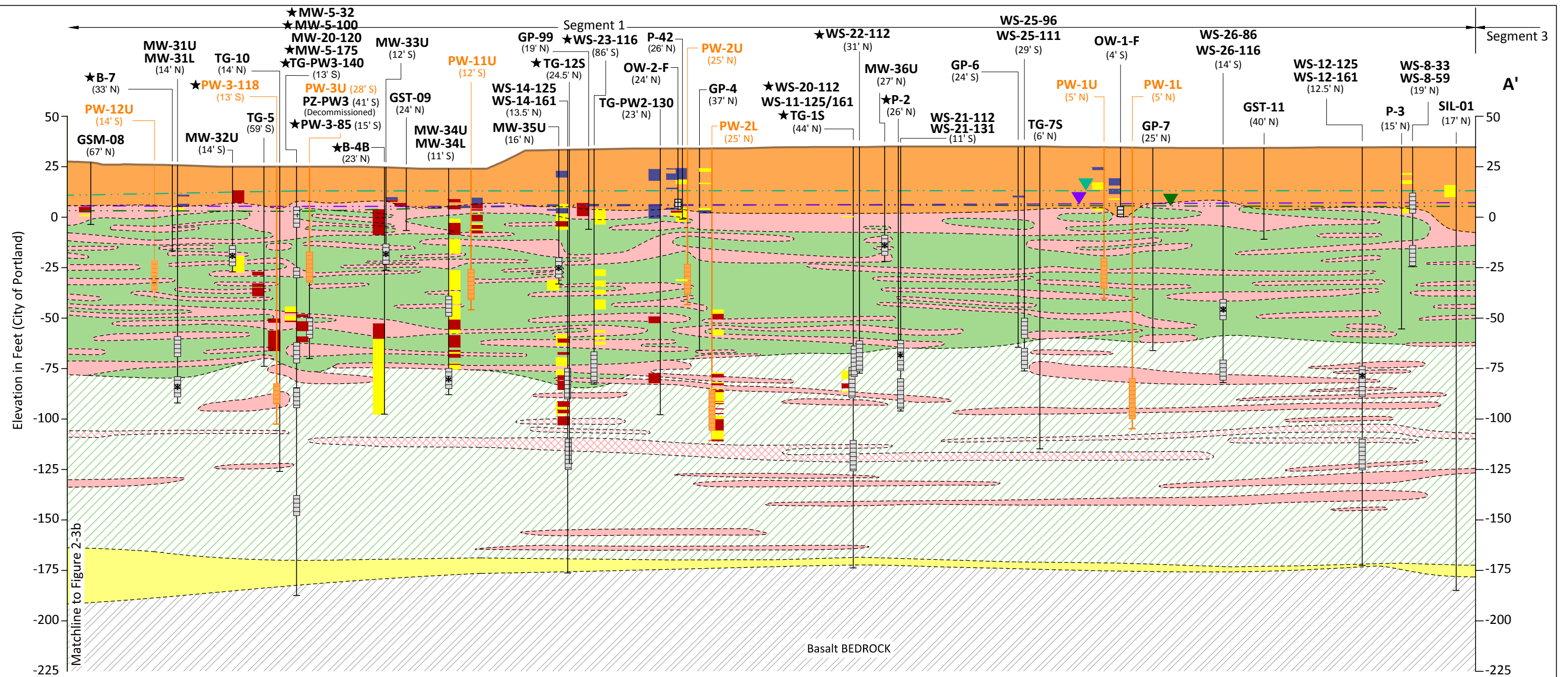


Figure 3a
 Geologic Cross Section A-A'
 Groundwater Source Control Extraction System Test Plan
 NW Natural Gasco Site

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Oct 08, 2013 10:59am heriksen



LEGEND:

- Fill WBZ** - Fill composed of gravel, silt, sand, metal, brick, and concrete debris
- Upper Alluvium WBZ** - Primarily fine to medium grained SAND and SILTY-SAND interbedded with thin silt and sandy-silt layers
- Lower Alluvium WBZ** - Primarily medium grained SAND with generally less than 5% fines.

- Aquitard** - Primarily SILT and SANDY-SILT interbedded with thin sand and silty-sand layers
- Primarily SILT and SANDY-SILT interbedded with thin sand and silty-sand layers
- Alluvial GRAVEL, sandy gravel, gravelly sand, and gravelly silt
- Basalt BEDROCK

- Potentiometric Surface of Surficial Fill (measured June 3, 2009)
- Potentiometric Surface of Surficial Fill (measured August 5, 2009)
- Potentiometric Surface of Alluvium (measured August 5, 2009)
- Existing Ground Surface

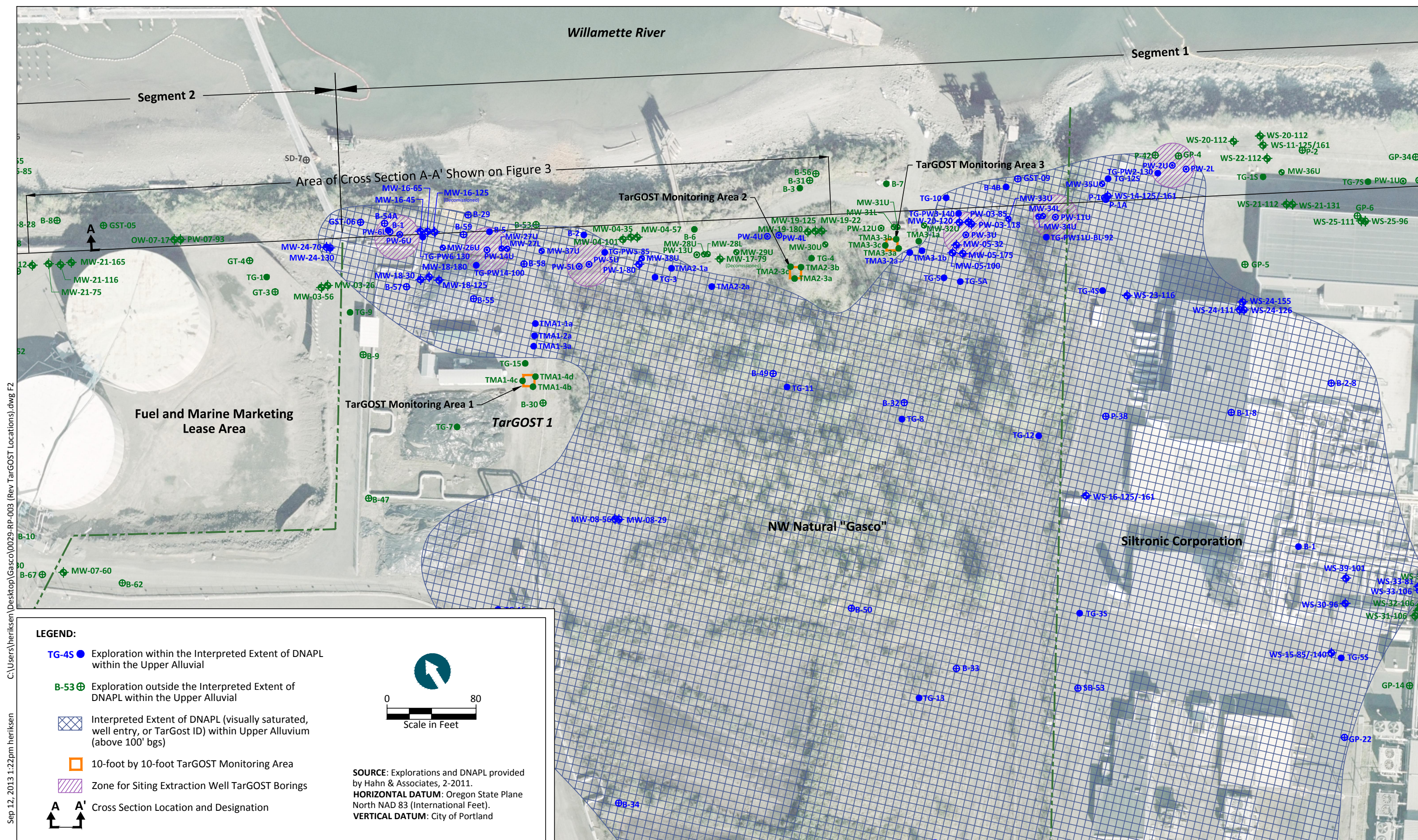
- MW-21-16** (57' E) — Boring ID
- Offset Distance in Feet
- Tar Interval
- Oil or Mixed Oil and Tar Interval
- Sheen Interval
- Well Screen
- * — Control Well



NOTE: Geologic contacts are inferred between borings.
★ Not used for geologic interpretation.



Figure 3c
Geologic Cross Section A-A'
Groundwater Source Control Extraction System Test Plan
NW Natural Gasco Site



APPENDIX A
NW NATURAL GASCO SITE –
UNCERTAINTY EVALUATION FOR
CONTROL WELLS OF THE
HYDRAULIC CONTROL AND
CONTAINMENT SYSTEM

MEMORANDUM

To:	Dana Bayuk, Oregon Department of Environmental Quality	Date:	February 15, 2013
From:	Michael Riley and Pradeep Mugunthan, Anchor QEA, LLC; Christopher Neville, S.S. Papadopoulos & Associates	Project:	000029-02.26
Cc:	John Edwards, John Renda, Carl Stivers, and Ben Hung, Anchor QEA, LLC		
Re:	NW Natural Gasco Site – Uncertainty Evaluation for Control Wells of the Hydraulic Control and Containment System		

As directed by the Oregon Department of Environmental Quality (DEQ), NW Natural has designed a groundwater hydraulic control and containment (HC&C) system as a source control measure to prevent upland groundwater from discharging to the Willamette River from the NW Natural Gasco Site (Site) in Portland, Oregon. The HC&C system is currently being installed at the Site. A main feature of the HC&C system is a series of extraction wells utilizing centrifugal pumps powered by variable frequency drive (VFD) motors to extract groundwater under time-varying river stage and tidal conditions in the river. The VFD system will be controlled by transducers in control wells located approximately midway between extraction wells. The control wells will be connected to a programmable logic control (PLC) system that will also be connected to a transducer in the river. The PLC will adjust the VFD pumps at the extraction wells to maintain lower water levels in the control wells than in the river and thereby maintain a gradient reversal from the river to the extraction wells. The target water elevation difference between control wells and the river is referred to as the elevation delta (ΔH). A larger ΔH will result in higher pumping rates and a stronger gradient reversal with more groundwater extraction of river water.

DEQ has raised concerns about how the ΔH value will be established and, in particular, how setting ΔH will account for uncertainty in water level measurement and time-varying conditions in the river (Bayuk 2012). In its August 2012 correspondence, DEQ raised the following specific items of concern with the understanding that other areas of concern could arise later:

- Accuracy of the transducers and transducer drift
- Accuracy of electronic depth-to-water probes
- Accuracy of the Site survey
- Daily tidal changes
- Seasonal river stage fluctuations
- Location and depth of a transducer-equipped installation relative to a control well/extraction well pair
- Use and reliability of the MODFLOW model for predicting small differences in water levels (e.g., on the order of a few tenths of a foot)

This set of topics has been grouped into the following three categories and is evaluated in the following sections: 1) topics related to the accuracy of water level measurements; 2) topics related to river stage; and 3) topics related to data interpretation. A summary of the topics and findings of this evaluation is presented in Table 1. NW Natural believes it is critically important for DEQ comments on this document to include confirmation that this is the final list of topics, or to notify us of any additional uncertainties that will need to be considered.

Table 1
NW Natural, Gasco, Groundwater Source Control
Summary of Potential Sources of Uncertainties in the Accuracy of Groundwater Level Data Identified by DEQ

Potential Sources of Uncertainty	Estimated Uncertainty (feet)	Comments
Accuracy of the Site survey from which groundwater elevations are determined	Approximately 0.01	Site-specific accuracy can be determined by conducting a level closure survey.
Accuracy of the transducers and transducer drift	± 0.015	<p>The accuracy of transducers is determined by the range of water levels and resolution of the instruments. This can be determined from manufacturer's specifications.</p> <p>The transducer accuracy can be documented at the time of installation by adjusting the transducer placement over a measured length.</p> <p>Drift is determined from periodic hand measurements, usually at the time that transducer data are downloaded. Transducer readings are corrected accordingly, and any adjustments or replacement of transducers are made in the field.</p>
Accuracy of electronic depth-to-water probes	± 0.02	Depth-to-water probes have been the industry standard for more than 30 years, and their performance is well established. Accuracy is largely dependent on the operator. Operator error can be quantified by having multiple readings taken by different members of the field crew.
Seasonal river stage fluctuations	Not a source of uncertainty	The variable rate pumping test conducted in April 2012 indicated that the control wells could accurately track fluctuations in river stage.
Daily tidal changes	Not a source of uncertainty	The variable rate pumping test conducted in April 2012 indicated that the control wells could accurately track fluctuations due to tidal changes.
Location and depth of a transducer-equipped installation relative to a control well/extraction well pair	Not a significant source of uncertainty	Model adjustments can be made to account for the location and depth of a water level monitoring well relative to control wells and pumping wells.
Use and reliability of the MODFLOW model for predicting small differences in water levels	To be determined	This uncertainty will be determined during model calibration to HC&C startup data.

Notes:

DEQ = Oregon Department of Environmental Quality

HC&C = hydraulic control and containment

ACCURACY OF WATER LEVEL MEASUREMENTS

This topic includes the accuracy of transducers, electronic depth-to-water probes, and the Site survey. These three areas of concern have readily quantifiable uncertainty and have been well studied and documented in the literature.

Transducer Accuracy and Drift

Transducers are programmed to respond to a range in water level data with accuracy given as the percent of the range. Typical accuracy is plus or minus (\pm) 0.05 percent of the range (i.e., Level Troll 700). The maximum range in river stage over the previous 25 years is approximately 30 feet. Therefore, a transducer with a 30-foot range would provide an accuracy of ± 0.015 feet.

Transducer drift can be examined when data are downloaded by comparing hand water level measurements to the transducer reading at that time and resetting the transducer accordingly. Wells that are directly connected to the PLC will not need manual data downloads. However, manual water levels should be taken at these wells when field crews download data from the wells that are not connected to the PLC. If drift is identified, the data can be reasonably adjusted by assuming a linear correction over the time interval from the previous data download. Large drift would indicate that the transducer should be replaced.

Electronic Depth-to-Water Probes

Electronic depth-to-water probes have been the industry standard for more than 30 years. The accuracy of a graduated electric tape is ± 0.01 feet for depth-to-water of fewer than 200 feet (see Attachment A). Sweet et al. found that, in practice, largely due to operator error, the precision of electronic water level probes is limited to ± 0.02 feet (see Attachment B). Field accuracy can be determined by having multiple depth-to-water readings taken by different members of the field crew.

Site Survey

The HC&C PLC determines the water level differential between control wells and the river. Therefore, the absolute elevation is less important than the accuracy of the survey. An error in the elevation of a benchmark will not affect the results because it is applied uniformly to all measuring points. The accuracy of the survey can be determined during the survey by conducting a circuit closure survey and recording the circuit closure error. This error is determined by starting the survey from a benchmark and conducting the level circuit and then ending by taking the elevation of the original benchmark. The difference between the actual

elevation of the benchmark and the elevation from the circuit closure gives the accuracy of the survey.

Acceptable level circuit closure error is based on the number of instrument setups to complete the circuit (see Attachment C). For ten setups, the acceptable level circuit closure error is approximately 0.01 feet.

RIVER STAGE FLUCTUATIONS

River stage fluctuations include both tidal fluctuations and seasonal changes in river stage. DEQ is concerned about uncertainty with respect to river stage fluctuations and the HC&C system concern the ability to maintain capture during rising and falling river stages.

Tidal Fluctuations

Tidal fluctuations occur twice a day, generally ± 2 feet. Groundwater response to tides is measured by the ratio of the water level fluctuation in a well compared to the stage change in the river, which is referred to as tidal efficiency. Wells with high tidal efficiency respond quickly to tidal changes. As observed in the VFD pumping test (Anchor QEA 2011), wells with high tidal efficiency closely track tidal fluctuations, and the variable frequency pumps did not have any difficulty in keeping up with the tidal fluctuations.

HC&C wells with low tidal efficiencies cannot be expected to keep up with tidal fluctuations, as the wells do not closely track tides under natural conditions. The effectiveness of the HC&C system at these wells needs to consider longer-term gradient controls. For these wells, the Serfes 3-day moving average method should be used to determine gradient reversal (Serfes 1990).

Due to the ability of control wells to track tidal changes in the river and the use of the Serfes method for determining gradients under tidal conditions, tidal fluctuations are not a source of uncertainty for evaluation of HC&C performance.

River Stage Fluctuations

Seasonal river stage changes occur over a period of days rather than hours. As observed during the variable frequency pumping tests, all nearshore alluvium water bearing zone wells tracked the non-tidal rising and falling river stage over the 9 days monitored for the tests.

Consequently, seasonal variations in river stages do not introduce an uncertainty in the use of water level data for evaluation of HC&C performance.

UNCERTAINTY IN DATA INTERPRETATION

Water level data collected by the transducer network and control wells, along with pumping rate information, will be used to determine the extent of groundwater containment by the HC&C system. The analysis will utilize the groundwater flow model developed for the Site as upgraded based on HC&C well boring and completion logs, and will be recalibrated to HC&C startup testing data. The data interpretation will account for the actual location and completion depth of wells and uncertainty in the groundwater model predictions.

Location and Depth of Monitoring Wells Relative to Control Well/Extraction Well Pairs

Water level data will be collected from a series of monitoring wells in addition to the HC&C control wells. Data from monitoring wells will be used in the calibration of the Site groundwater flow model. In addition, data collected during regular operation of the HC&C system will be used in periodic performance evaluations to demonstrate groundwater containment at the Site. It is expected that the groundwater flow model will use the USGS MODFLOW code, which is a block-centered flow code. This means that the model assumes that wells are located at the center of a model grid cell. In addition, the model assumes that a well is completed across the entire thickness of a model layer. The interpretation of model results needs to account for wells that are not located at cell centers and that are not completed across the full model layer.

Wells off-center from the cell center can be handled by interpolating model-predicted water levels across the model domain. The actual coordinates of the well are used in the interpolation to generate predicted water levels at a well location. The model calibration and performance evaluation will use the spatial interpolation for comparison of model results to well water level data.

The maximum difference between a model cell center and an actual well location is 14 feet based on the 20 by 20 feet grid spacing in the model. The error associated with a displacement of 14 feet would be small, except for areas of high gradient such as immediately adjacent to a pumping well where flow in all directions will be directed toward the pumping well. The minor error associated with well displacement from the cell center would be further reduced by

using spatial interpolation of predicted water levels. Consequently, well displacement is not a source of uncertainty that could affect predicting of groundwater capture by the HC&C system

The issue of wells that are not completed within a model layer can be addressed by several methods. If a well is considered particularly important with respect to predicting capture by the HC&C system, model layers can be adjusted such that the model layer extends from the top to the bottom of the well screen interval. This will eliminate uncertainty with respect to model and well construction. Alternatively, if a screen interval crosses model layers, the monitoring well can be assigned to a model layer that is farther from the layer in which the closest pumping well is located. This will result in less drawdown predicted at the monitoring well due to the greater distance from the pumping well and will, therefore, provide a conservatively low estimate of groundwater containment at this location. The data analysis may also indicate that a well is not as responsive to tidal and pumping stresses as expected, given its location and completion interval. This could result in redevelopment of the well or selection of a different well for evaluation of groundwater containment.

Use and Reliability of the MODFLOW Model

NW Natural has proposed to use the Site groundwater model as one tool for evaluating the effectiveness of the HC&C system. The model provides a useful tool for evaluating capture on a Site-wide and three-dimensional basis. DEQ has expressed a concern about the reliability of the model for predicting small changes in water level elevations, on the order of a few tenths of a foot.

The Site groundwater model has been used to assist in the design of the HC&C system. Previously, the model was used to evaluate the effect of groundwater pumping and nearshore containment walls of various depths. In the course of these model applications, the model was used to simulate various pumping tests. In the simulation of the pumping test at PW-4-118 conducted in July 2007, the model successfully represented the drawdown at the deepest well on the Site, MW-5-175, where the drawdown was only 0.2 feet (see Attachment D). The model-predicted drawdown was only approximately 0.02 feet less than the drawdown computed from the data. Based on this, the ability of the model to resolve water level differences of less than a few tenths of a foot has been demonstrated.

To increase the reliability of the model and reduce uncertainty in model predictions, the model is undergoing additional refinement to better represent the constructed HC&C system. These

changes are discussed in the memorandum *NW Natural Gasco Site Groundwater Model Update Plan* (Anchor QEA 2013). Following refinement of the model structure, the model will be calibrated to the HC&C startup test. This model calibration will include a transient model calibration to the actual time-varying pumping rates and groundwater levels at the HC&C control wells. The reliability and uncertainty associated with the model calibration will be documented in the calibration statistics between model predictions and data.

For prediction of groundwater containment, it is not only important to have reliable predictions of water levels but also representative predictions of hydraulic gradients. Therefore, model data analysis will be conducted as follows:

- Water levels predicted by the model will be compared to the data by comparing the measured hydrology data at a well to the interpolated model water level at the same location. The comparisons will include model data cross plots, statistical t-test (or an equivalent non-parametric test, depending on normality) of residuals, along with probability plots and conventional goodness-of-fit measures, such as root mean squared error, correlation analysis, and the Nash-Sutcliffe coefficient. The t-test and probability plots of the residuals will provide an indication of bias in model predictions and also the dispersion in the residual errors relative to measured data. The goodness-of-fit measures will provide a basis for assessing the ability of the model to explain the variability observed in the data.
- Model-predicted water level gradients will be compared to the gradients calculated from water level elevation data at the HC&C control wells and offshore piezometers and the observation wells located adjacent to the pumping wells. Predicted and observed distributions of the head difference will be compared through statistical t-tests (or an equivalent non-parametric test) and the suite of goodness-of-fit measures indicated above. This will provide a basis for assessing the reliability of the model in predicting gradient reversal.

Following these data analysis steps, the model will be used with particle tracking to illustrate the horizontal and vertical extent of the capture zone of the HC&C system. Based on this evaluation, ΔH may be adjusted at some control wells and will be increased in areas that have insufficient groundwater containment. In areas with adequate capture, the model will be used to estimate if ΔH can be reduced in some areas or adjusted among the control wells to provide more evenly distributed containment along the line of HC&C extraction wells.

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List of Attachments

Attachment A	Measuring Water Levels by Use of an Electric Tape, USGS, GWPD-4
Attachment B	Water Level Monitoring, Achievable Accuracy and Precision, NGWA
Attachment C	Levels at Gauging Stations, USGS, Techniques and Methods A-319
Attachment D	NW Natural, Gasco, Additional Groundwater Flow Analysis, SS Papadopoulos, 2008

PM:MR:cb:rrw

ATTACHMENT A
MEASURING WATER LEVELS BY USE
OF AN ELECTRIC TAPE, USGS,
GWPD-4

GWPD 4—Measuring water levels by use of an electric tape

VERSION: 2010.1

PURPOSE: To measure the depth to the water surface below land-surface datum using the electric tape method.

Materials and Instruments

1. An electric tape, double-wired and graduated in feet, tenths and hundredths of feet. Electric tapes commonly are mounted on a hand-cranked and powered supply reel that contains space for the batteries and some device (“indicator”) for signaling when the circuit is closed (fig. 1).
2. An older model electric tape, also known as an “M-scope,” marked at 5-foot intervals with clamped-on metal bands (fig. 2) has been replaced by newer, more accurate models. Technical procedures for this device are available from the procedures document archives.
3. A steel reference tape for calibration, graduated in feet, tenths and hundredths of feet
4. Electric tape calibration and maintenance equipment logbook
5. Pencil or pen, blue or black ink. Strikethrough, date, and initial errors; no erasures
6. Water-level measurement field form, or handheld computer for data entry
7. Two wrenches with adjustable jaws or other tools for removing well cap
8. Key for well access
9. Clean rag
10. Cleaning supplies for water-level tapes as described in the National Field Manual (Wilde, 2004)
11. Replacement batteries

Data Accuracy and Limitations

1. A modern graduated electric tape commonly is accurate to ± 0.01 foot.
2. Most accurate for water levels less than 200 feet below land surface.
3. The electric tape should be calibrated against an acceptable steel tape. An acceptable steel tape is one that is maintained in the office for use only for calibrating tapes, and this calibration tape never is used in the field.
4. If the water in the well has very low specific conductance, an electric tape may not give an accurate reading.
5. Material on the water surface, such as oil, ice, or debris, may interfere with obtaining consistent readings.
6. Corrections are necessary for measurements made from angled well casings.
7. When measuring deep water levels, tape expansion and stretch is an additional consideration (Garber and Koopman, 1968).

Advantages

1. Superior to a steel tape when water is dripping into the well or condensing on the inside casing walls.
2. Superior to a steel tape in wells that are being pumped, particularly with large-discharge pumps, where the splashing of the water surface makes consistent results by the wetted-tape method impossible. Also safer to use in pumped wells because the water is sensed as soon as



Figure 1. An electric tape or cable, double wired and marked the entire length in feet, tenths and hundredths of feet, that can be considered accurate to 0.01 foot at depths of less than 200 feet. Electric tapes commonly are mounted on a hand-cranked and powered supply reel that contains space for the batteries and some device (“indicator”) for signaling when the circuit is closed. Brand names are for illustration purposes only and do not imply endorsement by the U.S. Geological Survey. (Photographs used with permission of vendors.)

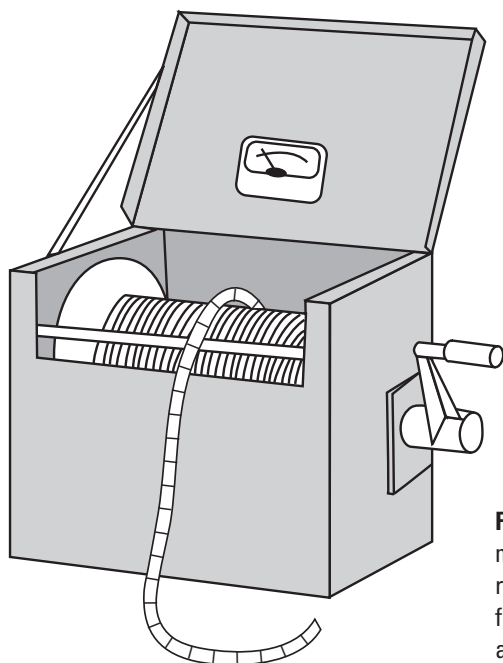


Figure 2. Older model electric tape, also known as “M-scope” marked at 5-foot intervals with clamped-on metal bands, has been replaced by newer, more accurate models. Technical procedures for this device are available from the procedures document archives.

the probe reaches the water surface and there is less danger of lowering the tape into the pump impellers.

3. Superior to a steel tape when a series of measurements are needed in quick succession, such as in aquifer tests, because the electric tape does not have to be removed from the well for each reading.

Disadvantages

1. Harder to keep calibrated than a steel tape.
2. Electric connections require maintenance.
3. Requires battery power.
4. Cable jacket is subject to wear and tear. Continuity of the electrical circuit must be maintained.

Assumptions

1. An established measuring point (MP) exists and the distance from the MP to the land-surface datum (LSD) is known. See GWPD 3 for the technical procedures on establishing a permanent MP.
2. The MP is clearly marked and described so that a person who has not measured the well will be able to recognize it.
3. The well is free of obstructions that could affect the plumbness of the steel tape and cause errors in the measurement.
4. The same field method is used for measuring depth below the MP, or depth relative to vertical datum, but with a different datum correction.
5. The tape is calibrated against a steel reference tape.
6. Field measurements will be recorded on paper forms. When using a handheld computer to record field measurements, the measurement procedure is the same, but the instructions below refer to a specific paper field form.

Tape Calibration And Maintenance

Before using an electric tape in the field, calibrate it against a steel reference tape. A reference tape is one that is maintained in the office only to calibrate other tapes.

1. Calibration of electric tape:

- Check the distance from the probe's sensor to the nearest foot marker on the tape to ensure that this distance puts the sensor at the zero-foot point for the tape. If it does not, a correction must be applied to all depth-to-water measurements.
- Compare length marks on the electric tape with those on the steel reference tape while the tapes are laid out straight on level ground, or compare the electric tape with a known distance between fixed points on level ground.
- Compare water-level measurements made with the electric tape with those made with a calibrated steel tape in several wells that span the range of depths to water that is anticipated. Measurements should agree to within ± 0.02 foot. If measurements are not repeatable to this standard, then a correction factor based on a regression analysis should be developed and applied to measurements made with the electric tape.

2. Using a repaired/spliced tape: If the tape has been repaired by cutting off a section of tape that was defective and splicing the sensor to the remaining section of the tape, then the depth to water reading at the MP will not be correct. To obtain the correct depth to water, apply the following steps, which is similar to the procedure for using a steel tape and chalk. Using the water-level measurement field form (fig. 3) to record these modifications:
 - Ensure that the splice is completely insulated from any moisture and that the electrical connection is complete.
 - Measure the distance from the sensing point on the probe to the nearest foot marker above the spliced section of tape. Subtract that distance from the nearest foot marker above the spliced section of tape. That value then becomes the "tape correction." For example, if the nearest foot marker above the splice is 20 feet, and the distance from that foot marker to the probe sensor is 0.85 foot, then the tape correction will be 19.15 feet. Write down the tape correction on the water-level measurement field form (fig. 3). Periodically recheck this value by measuring with the steel reference tape.
3. Maintain the tape in good working condition by periodically checking the tape for breaks, kinks, and possible stretch.
4. Carry extra batteries, and check battery strength regularly.
5. The electric tape should be recalibrated annually or more frequently if it is used often or if the tape has been subjected to abnormal stress that may have caused it to stretch.



WATER-LEVEL MEASUREMENT FIELD FORM Calibrated Electric Tape Measurement



SITE INFORMATION

SITE ID (C1)

--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Equipment ID

Date of Field Visit

Station name (C12)

WATER-LEVEL DATA

	1	2	3	4	5
Time					
Hold					
Tape correction					
WL below MP					
MP correction					
WL below LSD					

Measured by _____ COMMENTS* _____

*Comments should include quality concerns and changes in: M.P., ownership, access, locks, dogs, measuring problems, et al.

MEASURING POINT DATA (for MP Changes)

M.P. REMARKS (C324)

BEGINNING
DATE
(C321)

--	--	--	--	--	--

month

day

year

ENDING
DATE
(C322)

--	--	--	--	--	--

M.P. HEIGHT (C323)
NOTE: (-) for MP
below land surface

--	--	--	--	--	--

Final Measurement for GWSI

WATER LEVEL TYPE
CODE (C243)

L M S

below below sea
land meas. level
surface pt.DATE WATER LEVEL MEASURED
(C235)TIME
(C709)STATUS METHOD
(C238)TYPE
(C239)TYPE
(C243)WATER LEVEL
(C237)

--	--	--	--	--	--

month

day

year

--	--	--	--	--	--

--

--

--

--	--	--	--	--	--	--	--

(GWPD1)

(GWPD4)

METHOD OF WATER-LEVEL
MEASUREMENT (C239)

A	B	C	E	G	H	L	M	N	R	S	T	V	Z
airline,	analog,	calibrated	estimated,	pressure	calibrated	geophysi-	manometer,	non-rec.	reported,	steel	electric	calibrated	other
		airline,		gage,	press. gage,	cal logs,		gage,		tape,	tape,	elec. tape	

SITE STATUS
FOR WATER
LEVEL (C238)

D	E	F	G	H	I	J	M	N	O	P	R	S	T	V	W	X	Z	BLANK
dry,	recently	flowing,	nearby	nearby	injector	injector	plugged,	measure-	obstruc-	pumping,	recently	nearby	nearby	foreign	well	surface	other	static
	flowing,		flowing	recently	site,	site		ment	tion,	pumped,	pumped,	recently	recently	sub-	des-	water		
			flowing,	flowing,	monitor,	monitor,		discon.,				pumped,	pumped,	stance,	troyed,	effects,		

Figure 3. Water-level measurement field form for calibrated electric tape measurements. This form, or an equivalent custom-designed form, should be used to record field measurements.

Instructions

1. Check the circuitry of the electric tape before lowering the probe into the well by dipping the probe into tap water and observing whether the indicator needle, light, and (or) beeper (collectively termed the “indicator” in this document) are functioning properly to indicate a closed circuit. If the tape has multiple indicators (sound and light, for instance), confirm that they are operating simultaneously. If they are not, determine the most accurate indicator.
2. Make all readings using the same deflection point on the indicator scale, light intensity, or sound so that water levels will be consistent among measurements.
3. Lower the electrode probe slowly into the well until the indicator shows that the circuit is closed and contact with the water surface is made (fig. 4). Place the nail of the index finger on the insulated wire at the MP and read the depth to water.
4. Record the date and time of the measurement. Record the depth to water measurement in the row “Hold” (fig. 3). If the tape has been repaired and spliced or has a calibration correction (see the section above on using a repaired/spliced tape), subtract the “Tape Correction” value from the “Hold” value, and record this difference in the row “WL below MP” (fig. 3).
5. Record the MP correction length on the “MP correction” row of the field form (fig. 3). Subtract the MP correction length from the true “WL below MP” value to get the depth to water below or above LSD. The MP correction is positive if the MP is above land surface and is negative if the MP is below land surface (GWPD 3). Record the water level in the “WL below LSD” column of the water-level measurement field form (fig. 3). If the water level is above LSD, record the depth to water in feet above land surface as a negative number.
6. Pull the tape up and make a check measurement by repeating steps 3–5. Record the check measurement in column 2 of the field form. If the check measurement does not agree with the original measurement within 0.02 foot, continue to make measurements until the reason for lack of agreement is determined or the results are shown to be reliable. If more than two measurements are made, use best judgment to select the measurement most representative of field conditions. Complete the “Final Measurement for GWSI” portion of the field form.
7. After completing the water-level measurement, disinfect and rinse that part of the tape that was submerged below the water surface as described in the National Field Manual (Wilde, 2004). This will reduce the possibility of contamination of other wells from the tape. Rinse the tape thoroughly with deionized or tap water to prevent tape damage. Dry the tape and rewind onto the tape reel.

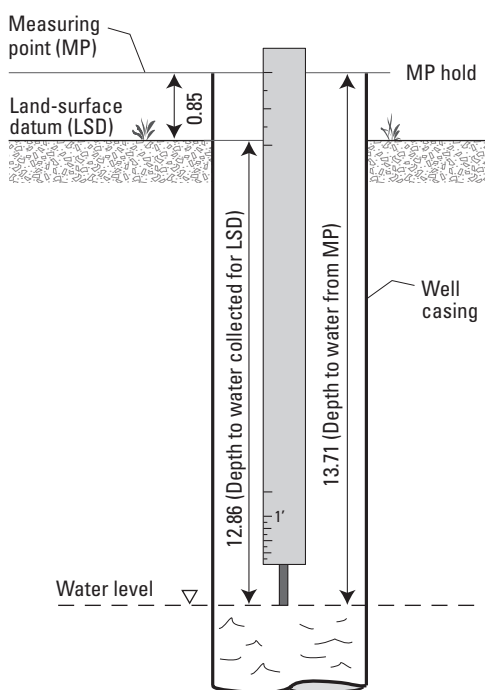


Figure 4. Water-level measurement using a graduated electric tape.

Data Recording

All calibration and maintenance data associated with the electric tape being used are recorded in the calibration and maintenance equipment logbook. All data are recorded in the water-level measurement field form (fig. 3) to the appropriate accuracy for the depth being measured.

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ATTACHMENT B
WATER LEVEL MONITORING,
ACHIEVABLE ACCURACY AND
PRECISION, NGWA

H. Randy Sweet,¹ Gerritt Rosenthal,² and Dorothy F. Atwood³

Water Level Monitoring—Achievable Accuracy and Precision

REFERENCE: Sweet, H. R., Rosenthal, G., and Atwood, D. F., "Water Level Monitoring—Achievable Accuracy and Precision," *Ground Water and Vadose Zone Monitoring, ASTM STP 1053*, D. M. Nielsen and A. I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 178–192.

ABSTRACT: Measurement of the depth to ground water is a basic element in all hydrogeologic investigations providing data for gradient, flow direction, seepage velocity, and aquifer constant calculations.

The U.S. Environmental Protection Agency (EPA) Technical Enforcement Guidance Document (TEGD) specifies a measurement accuracy goal of ± 0.01 ft for Resource Conservation and Recovery Act (RCRA) facilities. This accuracy goal may be unrealistic, since measurements are limited by their precision, and both accuracy and precision are affected by random and systematic sources of error and uncertainty.

Random precision uncertainties include instrument sensitivities, the measuring point location, and operator technique. Random accuracy problems include short-term climatic effects (precipitation, temperature, barometric pressure) and instrument calibration. Experience has demonstrated that these accumulated uncertainties range from ± 0.02 to ± 0.20 ft.

Systematic errors are both anthropogenic and site related and include surveying accuracy, well deviation from vertical, instrument deterioration (e.g., cable stretching), and special site problems (multiphase liquids, high gas pressures, foaming, and other problems).

These errors may increase inaccuracy or make readings highly variable. The cumulative uncertainty from both random and systematic error sources is ± 0.10 to ± 0.30 ft for a "pristine" shallow, unconfined aquifer, while for difficult installations or where anthropogenic factors are not well controlled, the accumulated error may be several feet.

This paper describes sources of error and uncertainty and reports on several practical experiments to quantify the uncertainty in water table measurements. The importance of understanding these sources in setting accuracy goals is stressed.

KEY WORDS: ground water, conductive probes, water level indicators, transducers, data loggers, measurement accuracy, precision, error

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Roger J. Henning¹

Presentation of Water Level Data

REFERENCE: Henning, R. J., "Presentation of Water Level Data," *Ground Water and Vadose Zone Monitoring, ASTM STP 1053*, D. M. Nielsen and A. I. Johnson, Eds., American Society for Testing and Materials, Philadelphia, 1990, pp. 193-209.

ABSTRACT: Most common methods used to present water-level data are graphical. These include various kinds of hydrographs, such as those showing water level versus time, draw-down versus time or distance, or the level in one well versus that in another. Contour plots in map view are essential for evaluating ground-water flow. Water levels on cross sections are useful in evaluating the relationship between stratigraphic units and water levels. Flow nets can be used in plan or cross-sectional view to estimate flow lines and possible pathways for seepage.

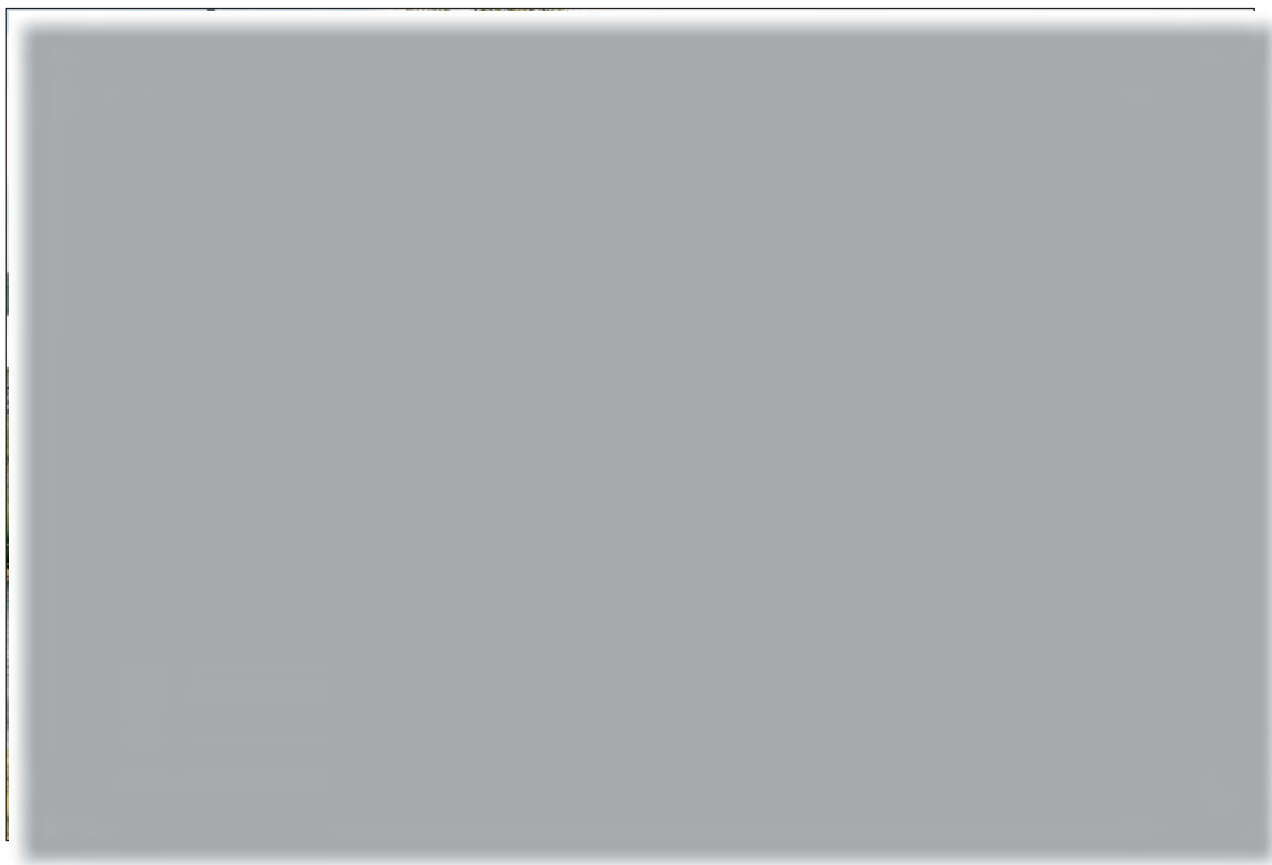
KEY WORDS: ground water, water level, data presentation, graphical presentation, tabular presentation

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ATTACHMENT C
LEVELS AT GAUGING STATIONS,
USGS, TECHNIQUES AND METHODS
A-319

Levels at Gaging Stations

**Chapter 19 of
Section A, Surface-Water Techniques
Book 3, Applications of Hydraulics**



Techniques and Methods 3–A19

Cover: View of levels being run at U.S. Geological Survey streamflow-gaging station 10156000, Snake Creek near Charleston, Utah.
Photograph taken by K. Michael Nolan, U.S. Geological Survey, June 30, 2010.

Back Cover: USGS topographic field party, circa 1925, with a Wye level on a tripod and two stadia rods. Photograph by U.S. Geological Survey.

Levels at Gaging Stations

By Terry A. Kenney

Chapter 19 of

Section A, Surface-Water Techniques

Book 3, Applications of Hydraulics

Techniques and Methods 3–A19

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2010

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Kenney, T.A., 2010, Levels at gaging stations: U.S. Geological Survey Techniques and Methods 3-A19, 60 p.

Preface

This series of manuals on techniques and methods (TM) describes approved scientific and data-collection procedures and standard methods for planning and executing studies and laboratory analyses. The material is grouped under major subject headings called “books” and further subdivided into sections and chapters. Section A of book 3 is on surface-water techniques.

The unit of publication, the chapter, is limited to a narrow field of subject matter. These publications are subject to revision because of experience in use or because of advancement in knowledge, techniques, or equipment, and this format permits flexibility in revision and publication as the need arises. Chapter A19 of book 3 (TM 3–A19) deals with levels at gaging stations. The original version of this chapter was published in 1990 as U.S. Geological Survey (USGS) Techniques of Water-Resources Investigations, chapter A19 of book 3. New and improved equipment, as well as some procedural changes, have resulted in this revised second edition of “Levels at gaging stations.”

This edition supersedes USGS Techniques of Water-Resources Investigations 3A–19, 1990, “Levels at streamflow gaging stations,” by E.J. Kennedy.

This revised second edition of “Levels at gaging stations” is published on the World Wide Web at <http://pubs.usgs.gov/tm/tm3A19/> and is for sale by the U.S. Geological Survey, Science Information Delivery, Box 25286, Federal Center, Denver, CO 80225.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$$

Levels at Gaging Stations

By Terry A. Kenney

Abstract

Operational procedures at U.S. Geological Survey gaging stations include periodic leveling checks to ensure that gages are accurately set to the established gage datum. Differential leveling techniques are used to determine elevations for reference marks, reference points, all gages, and the water surface. The techniques presented in this manual provide guidance on instruments and methods that ensure gaging-station levels are run to both a high precision and accuracy. Levels are run at gaging stations whenever differences in gage readings are unresolved, stations may have been damaged, or according to a pre-determined frequency. Engineer's levels, both optical levels and electronic digital levels, are commonly used for gaging-station levels. Collimation tests should be run at least once a week for any week that levels are run, and the absolute value of the collimation error cannot exceed 0.003 foot/100 feet (ft).

An acceptable set of gaging-station levels consists of a minimum of two foresights, each from a different instrument height, taken on at least two independent reference marks, all reference points, all gages, and the water surface. The initial instrument height is determined from another independent reference mark, known as the origin, or base reference mark. The absolute value of the closure error of a leveling circuit must be less than or equal to $0.003\sqrt{n}$ ft, where n is the total number of instrument setups, and may not exceed |0.015| ft regardless of the number of instrument setups. Closure error for a leveling circuit is distributed by instrument setup and adjusted elevations are determined. Side shots in a level circuit are assessed by examining the differences between the adjusted first and second elevations for each objective point in the circuit. The absolute value of these differences must be less than or equal to 0.005 ft. Final elevations for objective points are determined by averaging the valid adjusted first and second elevations. If final elevations indicate that the reference gage is off by |0.015| ft or more, it must be reset.

Introduction

At gaging stations where water-surface elevation or stage is measured, the U.S. Geological Survey (USGS) sets gages to read the stage above a specified reference surface called the gage datum (Kennedy, 1990). Equipment in most gaging stations measures and records stage at a frequency of 15 minutes. At streamflow gaging stations, discrete measurements of streamflow, made by hydrographers, are paired with a representative stage value. Over time, these pairings define a site-specific stage-discharge relation to which recorded stage values are applied to obtain a continuous streamflow record. To provide accurate and relevant data, it is imperative that gages agree with the established gage datum for the life of the station. To check and ensure that gages are properly set to gage datum, differential leveling techniques are used. Levels are run at gaging stations according to a standard set of frequency requirements, when unresolved gage reading differences have been identified, or when the station has been damaged.

Purpose and Scope

The purpose of this manual is to document the procedures that should be followed when running levels to check that gages are set to the established gage datum. Leveling equipment is discussed, along with specific precision requirements, desired accuracy, and calibration requirements. The required frequency for running gaging-station levels is outlined and presented in an easy to follow decision tree. The procedure for running levels at gaging stations is described in detail and illustrated in example level circuits. Specific error tolerances for both circuit closure and objective-point elevation differences are presented. Methods for taking foresights to various types of gages are discussed, and finally, office procedures associated with gaging-station levels are outlined. This manual describes new procedures for running levels at gaging stations that supersede those described by the previous USGS Techniques of Water-Resources Investigations Report "Levels at Streamflow Gaging Stations" by E.J. Kennedy (1990).

Differential Leveling and Leveling Equipment

Differential leveling is the process of measuring the vertical difference between a point of unknown elevation and a point of known elevation (McCormac, 1983). By measuring this difference, an elevation can be determined for the point of unknown elevation. At gaging stations, this measurement is most commonly made using an engineer’s level and a calibrated leveling rod (fig. 1). The engineer’s level is set up about equidistant from the point of known elevation and the point(s) of unknown elevation. A shot from the engineer’s level is first made to a leveling rod that is held on the known elevation point. This reading on the leveling rod is called a backsight (BS). The BS, which is the vertical distance of the engineer’s level above this point, is added to the known elevation of that point to determine the elevation of the engineer’s level, or the height of the instrument. Shots are then made from the engineer’s level to the leveling rod that is held on point(s) of unknown elevation. These readings are called foresights. A foresight (FS) is the distance of the engineer’s level above the point and is subtracted from the instrument height to determine elevation.

Differential leveling techniques are used at gaging stations to determine elevations for reference marks, reference points, gages, and the water surface. Reference marks are objects (for example, brass tablets, steel rods, or bolts) that are installed in the most stable locations near the gage and are used to adjust the gages as necessary to keep them in agreement with the gage datum (Kennedy, 1990). Reference

points are objects (for example, bolts, nails, or screws) that are installed in locations to facilitate the determination of gage heights by measuring their distance from the water surface. A variety of engineer’s levels and leveling rods can be used to run levels at streamflow-gaging stations. The USGS reports stage at most gaging stations in increments of 0.01 ft. Therefore, gaging-station levels, which are used to verify that gages agree with the gage datum, must be measured at a higher level of precision and accuracy. Precision describes the closeness of one measurement to another while accuracy describes how close a given measurement is to the true value (McCormac, 1983). The precision required of gaging-station levels is 0.001 ft, while the desired accuracy is less than 0.010 ft. Instruments selected for running levels at gaging stations must be capable of meeting these precision and accuracy requirements.

Level Instruments

Many surveying instruments are available that have several different equipment options and can perform a variety of surveying tasks. Levels at gaging stations require measurements of vertical distance and do not need measurements of horizontal distance or horizontal angle. Engineer’s levels are the most common instruments used for running levels at gaging stations. Most engineer’s levels meet the desired accuracy of less than 0.010 ft and the required precision of 0.001 ft for gaging-station levels. Surveying technology is continually changing, and other types of surveying instruments, such as tilting instruments, may be capable of meeting these accuracy and precision standards.

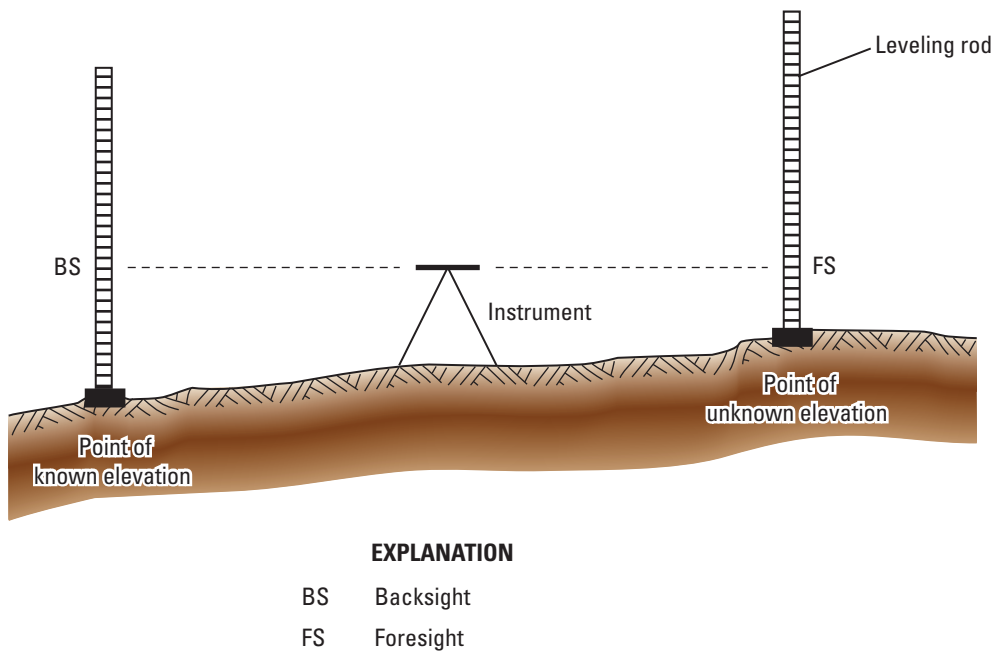


Figure 1. Differential leveling using an engineer’s level and leveling rods.

The techniques and methods presented in this manual provide guidance on using engineer's levels that ensures gaging-station levels are run to a high level of precision and accuracy. Before other types of surveying instruments are used for running gaging-station levels, techniques and methods specific to those instruments that ensure precision and accuracy requirements are met must be rigorously documented. Engineer's levels, which are sometimes referred to as line or spirit levels, can be classified in two general categories: optical levels and electronic digital levels.

Optical Levels

Optical levels ([fig. 2](#)) are used to manually read the leveling rod that is held on an objective point. When using an optical level, the operator reads the value off the rod at the cross hair of the level. Self-reading rods used in gaging-station levels are graduated to 0.01 ft. Precision requirements call for the operator of an optical level to estimate measurements within 0.001 ft. The ability to accurately estimate to 0.001 ft is determined by the distance from the instrument to the rod, the magnification power of the level's optics, and environmental conditions, such as the presence of heat waves. In general, the magnification of optical levels is about 30 times and allows readings as precise as 0.001 ft up to a distance of about 150 ft. Most modern optical levels are automatic, or self-leveling — the instrument levels itself precisely after being leveled manually with its circular (bull's eye) level (Kennedy, 1990). Many older optical levels, such as the Dumpy level, are not self-leveling and are time-consuming to set up and level. These older instruments are also easily knocked out of level, which can introduce unquantified errors into the leveling circuit.

Electronic Digital Levels

Electronic digital levels ([fig. 3](#)) automatically read a bar-code leveling rod ([fig. 4](#)) held on an objective point. When using an electronic digital level, the operator sights in the bar-code leveling rod using the optical view finder and then interrogates the instrument to make a measurement. The instrument then shows the value on its digital display screen. Many electronic digital levels are equipped with logging and computational functions that can be used when running levels. Electronic digital levels contain optical systems that also allow the level to be used manually. Like optical levels, distances to objective points and environmental conditions can limit the utility of electronic digital levels. Electronic digital levels provide some distinct advantages over optical levels; for example, because the instrument automatically reads the leveling rod, any subjectivity in manually estimating the measurement to 0.001 ft is removed. Similarly, the potential for misreading the leveling rod is eliminated when using electronic digital levels. When using data-logging features common to many electronic digital levels, errors associated with manually transcribing measurements can also be eliminated. A disadvantage of electronic digital levels is that the electronic nature of these instruments introduces the potential for system failures to occur while in the field. Fortunately, the optical capability serves as a backup to the electronic system. It is common when running levels at gaging stations to use a secondary device, such as a steel tape, to take shots on objects located in places where a rod cannot be placed. Further, FSs to some objects (such as wire-weight gages) are made by sighting in the object at the cross hair of the instrument. Digital systems, which require a bar-code rod, cannot be used for such shots. For these reasons, both the optical and the digital systems of electronic digital levels must be maintained and tested frequently.



Figure 2. Optical levels.

4 Levels at Gaging Stations



Figure 3. Electronic digital levels.

Parallax

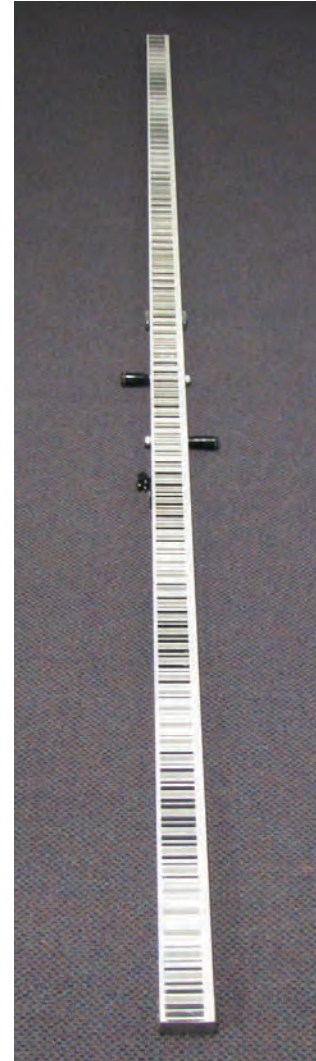
A sharply focused level is important for accurate readings of the leveling rod. A properly focused instrument locates the graduations of the leveling rod at the plane of the cross hairs. Parallax is the relative movement of the image of the leveling rod with respect to the cross hairs as the observer's eye moves. This is caused by the objective lens not being focused on the leveling rod (Kennedy, 1990). To check for parallax, slightly move your eye up and down while sighting in a leveling rod. If the rod appears to move with respect to the cross hair, parallax is present. Parallax usually can be eliminated by adjusting the objective focus. Diligence in refocusing the instrument for all readings and checking for parallax will eliminate erroneous measurements associated with improper focus.

Checking the Engineer's Level

An engineer's level is set up to measure the vertical distance from objective points to the level plane of the instrument. When applying the techniques of differential leveling, a properly leveled instrument is assumed to be on a horizontal plane at the determined elevation of the instrument or instrument height. Collimation error is a measurement of the inclination of a level's line of sight (Breed and others, 1970; McCormac, 1983; Kennedy, 1990), or the deviation from the horizontal plane. Collimation error is reported as a vertical deviation over a set distance, such as 0.xxx ft per 100 ft. If horizontal distances from the instrument to each object that a FS or BS is taken on are known, collimation corrections can be computed and applied. However, levels at gaging stations do not require measurements of horizontal distance, and therefore, the collimation error of the instrument is preserved in all measurements and is not corrected for.



Figure 4. Bar-code leveling rods. A. separated multi-section rod showing the self-reading rod scale on the second side.



Collimation error of an engineer's level is determined by running a fixed-scale test, a two-peg test, or another accepted collimation test. These tests check how true the instrument is sighting on a horizontal plane. Given the precision with which gaging-station levels are run (0.001 ft) and the criteria that determine a valid level run at a gaging station (these are outlined in detail in the section on "[Assessing a Level Circuit and Adjusted Elevation](#)"), the tolerance for the collimation error of an instrument cannot exceed the absolute value ($| |$) of 0.003 ft/100 ft. Instruments possessing collimation errors greater than $|0.003|$ ft/100 ft should be adjusted by qualified personnel or by a certified facility. Following any adjustments made to an instrument, a collimation test must be performed and documented to verify that the instrument was adjusted correctly.

The criteria for an acceptable level run include a limit on circuit-closure error and a maximum difference between the first and second elevations of any objective point in the level circuit. Conditions exist that can cause an instrument with a collimation error greater than $|0.003|$ ft/100 ft to yield results that meet the criteria for an acceptable level circuit and yet still produce final elevations that are incorrect because of the collimation error (see section on "[Collimation Error and Balanced Sightline Distances](#)"). In order to minimize errors associated with instrument calibration, a collimation test (fixed-scale, peg, or other accepted test) must be performed and documented at least once per week (National Oceanic and Atmospheric Administration, 1981; Federal Geodetic Control Committee, 1984) for each week that gaging-station

6 Levels at Gaging Stations

levels are run. There should not be more than 7 days between a collimation test and a set of levels. If a level is found to have a collimation error greater than $[0.003]$ ft/100 ft, all gaging-station levels run since the previous collimation test must be discarded and re-run. For this reason, it is recommended to run collimation tests more frequently. When electronic digital levels are used, these tests should be done for both the optical and digital systems.

Fixed-Scale Test

A fixed-scale test uses two mounted rod scales set to the same datum and spaced about 120 ft apart to determine the collimation error of an instrument ([fig. 5](#)). A fixed-scale test can be set up outdoors between trees, deeply set posts, or buildings at a reasonably level location, or can be set up indoors; for example, between columns or doorframes in a long corridor of a large building (Kennedy, 1990). To install the scales, place the instrument equidistant from the mounting locations. Install each scale such that the readings from the level to each scale are equal. To test the collimation of the level, set it up as close as possible to one scale. Read each scale from this location, and measure the horizontal distances to each scale. The length of d_2 should not exceed 110 ft to avoid curvature and refraction effects. Horizontal distances can be determined using the stadia hairs of the level, the distance reported by an electronic digital level, or a measuring tape. From these readings, the collimation error can be computed using the equation (Kennedy, 1990):

$$c = 100 * \left[\frac{(R_1 - R_2)}{(d_2 - d_1)} \right], \quad (1)$$

where

- c is the collimation error, in unit length per 100 unit lengths,
- R_1 is the reading obtained from the near rod scale, in unit length,
- R_2 is the reading obtained from the far rod scale, in unit length,
- d_1 is the distance to the near rod scale, in unit length, and
- d_2 is the distance to the far rod scale, in unit length, which should be less than 110 ft.

If the absolute value of the collimation error is greater than 0.003 ft/100 ft, the level must be adjusted. A diagram of a fixed-scale test showing the variables of equation 1 is shown in [figure 5](#). A fixed-scale test form is provided in [appendix A](#).

Peg Test

A peg test does not require scales to be mounted and can be run with the instrument and rod in any reasonably level location. Several versions of peg tests are used. The one described here, commonly referred to as a two-peg test, was adapted from the USGS Geography Discipline, formerly known as the USGS Survey and National Mapping Division (Kennedy, 1990). Two pegs or marks should be established and spaced about 120 ft apart ([fig. 6](#)). The instrument is set up as close as possible to one of the pegs. Shots are taken to the rod held on the near peg and the far peg. Distances from the instrument to the pegs are measured, using the stadia hairs, the digital system, or a measuring tape. The instrument is then moved as near as possible to the other peg, and again shots are taken to each and distances are measured. From these measurements the collimation error can be computed using the equation (Kennedy, 1990):

$$c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right], \quad (2)$$

where

- c is the collimation error, in unit length per 100 unit lengths,
- R_1 is the reading taken on the near peg from the first instrument setup, in unit length,
- R_2 is the reading taken on the far peg from the first instrument setup, in unit length,
- R_3 is the reading taken on the near peg from the second instrument setup, in unit length,
- R_4 is the reading taken on the far peg from the second instrument setup, in unit length,
- d_1 is the distance to the near peg from the first instrument setup, in unit length,
- d_2 is the distance to the far peg from the first instrument setup, in unit length,
- d_3 is the distance to the near peg from the second instrument setup, in unit length, and
- d_4 is the distance to the far peg from the second instrument setup, in unit length.

The average of d_2 and d_4 should be less than 110 ft to avoid curvature and refraction effects. If the absolute value of the collimation error is greater than 0.003 ft/100 ft, the instrument must be adjusted. A diagram of a peg test showing the variables of equation 2 is shown in [figure 6](#). A peg test form is provided in [appendix B](#) and is also contained in the Gaging Stations Level Notes form ([appendix C](#)).

Manufacturer-Recommended Collimation Test

Some manufacturers of level instruments provide a recommended method for testing and adjusting for

collimation error. Some of the electronic digital levels contain preprogrammed tests and adjustment routines that provide for efficient and convenient collimation checks. Some preprogrammed checks may require the instrument to be located a specified distance from the rod. If manufacturer-recommended methods meet the 0.001-ft precision and the less than 0.010-ft accuracy requirements for gaging-station levels and report collimation error as a vertical deviation over a specified distance, they can be used as the weekly collimation test. Weekly tests are required for both the optical and digital systems of the electronic instruments.

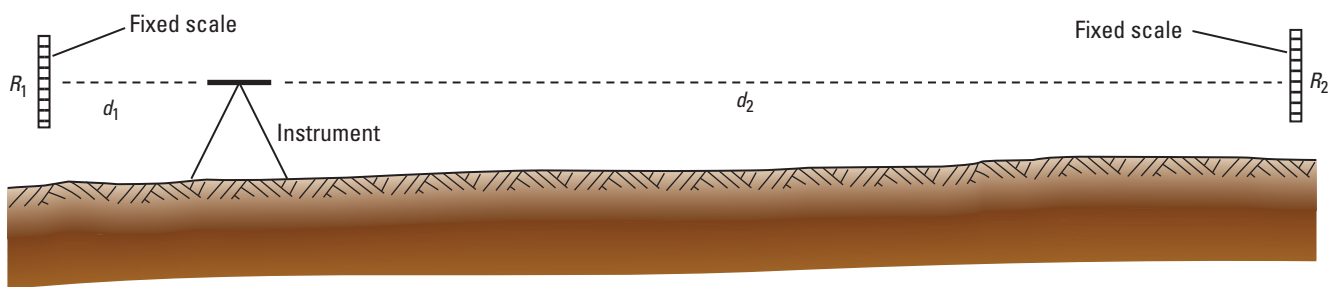


Figure 5. Engineer's level and rod scales set up for the fixed-scale test. R , the reading obtained from a rod scale; d , the distance to a rod scale. Modified from Kennedy (1990).

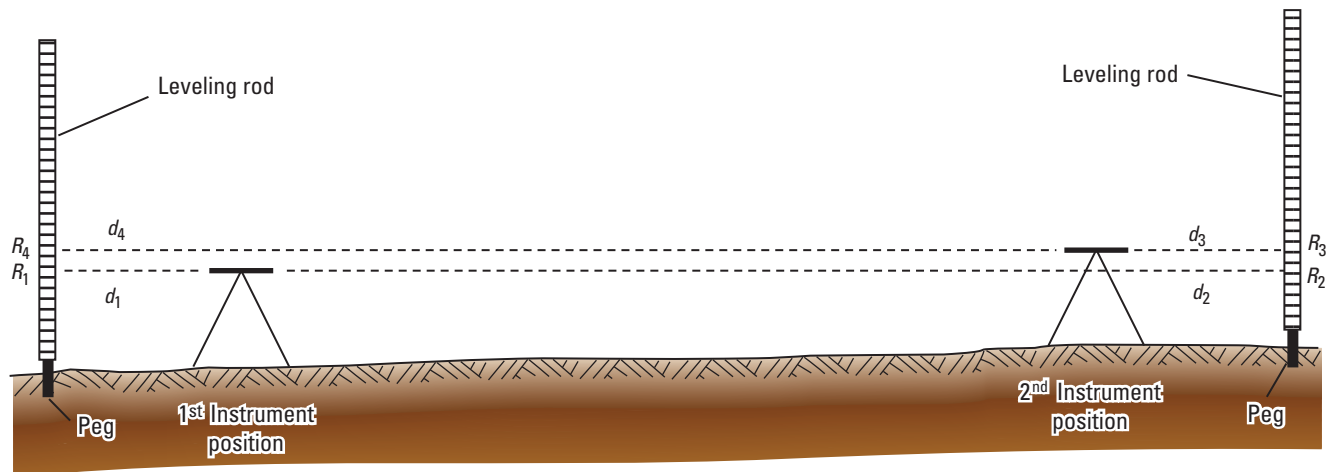


Figure 6. Engineer's level and leveling rods set up for the two-peg test. R , the reading obtained from a leveling rod; d , the distance to a peg. Modified from Kennedy (1990).

Collimation Error and Balanced Sightline Distances

Collimation error is a measure of the inclination of a level's line of sight. Unless corrected using measurements of horizontal distance, this systematic error is preserved in all measurements made with the level. Balancing the sightline distances to all objects to which shots are taken minimizes the effects of collimation error on final elevations. However, balancing sightline distances in a gaging-station level circuit is often not feasible. Under ideal conditions when sightline distances are perfectly balanced, collimation error preserved in FSs and BSs does not affect the final computed elevations. An example is an instrument that has a high collimation error of 0.010 ft/100 ft and sightline distances that equal 100 ft ([table 1](#)). Each BS and FS shows an error of 0.010 ft, because the instrument has a collimation error of 0.010 ft/100 ft and the distances are all 100 ft. Even though each shot contains collimation error, because the horizontal distances are equal, the error in each shot is equal. The collimation error indicates that the line of sight of the level is angled downwards causing readings of the leveling rod to be 0.010 ft low. Because the errors are equal for each shot, the true differences in elevation between the objective points can be accurately determined, and therefore, the final elevations of the objective points are the true elevations and the circuit-closure error is 0.000 ft. If this were a level circuit, ideally the level would not be used because the absolute value of the collimation error is greater than $|0.003|$ ft; however, because the sightline distances are perfectly balanced, the collimation error does not adversely affect the final elevations because the true differences in elevation between the objective points are determined in this circuit.

Collimation error begins to have a profound effect on final elevations when sightline distances are extremely unbalanced. However, the effect of collimation error can be masked when the distances between the instrument and the objective points remain the same for the second instrument setup. [Table 2](#) provides an example of how the effects of collimation error can go unnoticed. This example uses the same level circuit as the previous example, but sightline distances range from 10 to 200 ft. In this circuit, the distance to each of the objects remained the same for the second instrument setup. Errors contained in each BS and FS ranged from 0.001 to 0.020 ft. In a real gaging-station level circuit, these errors would not be known because horizontal distances are not measured. The two elevations acquired for each objective point differ from the true elevations, yet the closure error is 0.000 ft. In this example circuit, an instrument with a large unknown collimation error was used, and unless a comparison was made with the historical elevations, one would assume that the level circuit met the criteria for a valid level circuit of closure error and the difference between adjusted first and second objective point elevations (discussed in detail below). This introduces the potential for gages to be set or adjusted incorrectly during a level run.

The sightline distances should be inverted in order to reveal collimation errors in a circuit consisting of unbalanced sightline distances, which, as shown above, can produce erroneous final elevations. In the previous example with unbalanced sightline distances, the second instrument setup was located in the same position as the first instrument setup. The level circuit appeared to be valid, as evidenced by a closure error of 0.000 ft and no differences between first and second elevations for each objective point, yet the final

Table 1. Notes for gaging station levels run when all sightline distances are equal and the instrument used has a collimation error of 0.01 foot per 100 feet.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. BS, backsight; HI, height of instrument; FS, foresight; RM, reference mark; TP, turning point; NA, not applicable]

Object	Distance from instrument to object	BS error ¹	BS	HI	FS error ¹	FS	Elevation	Closure error	1st and 2nd elevation differences	True elevations	Difference from true elevation
RM1 (origin)	100	0.010	5.260	105.260	0.010	NA	² 100.000	NA	NA	100.000	NA
RM2	100	NA	NA	NA	0.010	7.121	98.139	NA	NA	98.139	0
RM3	100	NA	NA	NA	0.010	2.042	103.218	NA	NA	103.218	0
TP	100	NA	NA	NA	0.010	3.343	101.917	NA	NA	101.917	0
Instrument moved and re-leveled											
TP	100	0.010	4.343	106.260	0.010	NA	101.917	NA	NA	101.917	0
RM3	100	NA	NA	NA	0.010	3.042	103.218	NA	0	103.218	0
RM2	100	NA	NA	NA	0.010	8.121	98.139	NA	0	98.139	0
RM1	100	NA	NA	NA	0.010	6.260	100.000	0.000	NA	100.000	0

¹ Computed from the collimation error and the distance from the instrument to the object.

² Given elevation in the level circuit.

Table 2. Notes for gaging station levels run when sightline distances between the instrument and objects vary in the same order for two setups and the instrument used has a collimation error of 0.01 foot per 100 feet.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. Distances from the instrument to each object remained the same after the instrument was moved. BS, backsight; HI, height of instrument; FS, foresight; RM, reference mark; TP, turning point; NA, not applicable]

Object	Distance from instrument to object	BS error ¹	BS	HI	FS error ¹	FS	Elevation	Closure error	1st and 2nd elevation differences	True elevation	Difference from true elevation
RM1 (origin)	10	0.001	5.251	105.251	0.001	NA	² 100.000	NA	NA	100.000	NA
RM2	100	NA	NA	NA	0.010	7.121	98.130	NA	NA	98.139	-0.009
RM3	150	NA	NA	NA	0.015	2.047	103.204	NA	NA	103.218	-0.014
TP	200	NA	NA	NA	0.020	3.353	101.898	NA	NA	101.917	-0.019
Instrument moved and re-leveled											
TP	200	0.020	4.353	106.251	0.020	NA	101.898	NA	NA	101.917	-0.019
RM3	150	NA	NA	NA	0.015	3.047	103.204	NA	0.000	103.218	-0.014
RM2	100	NA	NA	NA	0.010	8.121	98.130	NA	0.000	98.139	-0.009
RM1	10	NA	NA	NA	0.001	6.251	100.000	0.000	NA	100.000	0.000

¹ Computed from the collimation error and the distance from the instrument to the object.

² Given elevation in the level circuit.

elevations were incorrect, because the FS errors caused by the collimation error of the instrument were equal for the two shots taken to each objective point.

[Table 3](#) shows an example of the same level circuit run with an instrument with the same collimation error of 0.010 ft/100 ft, but with the sightline-distances inverted so that the object farthest from the initial instrument setup is closest to the instrument for the second setup. The range of error contained in the FSs and BSs associated with the collimation error of the instrument is similar to those in the previous example because the same distances were used. Again, these errors would not be known because the horizontal distances are not measured when levels are run at gaging stations. By inverting the sightline distances a significant closure error is revealed. If this example were an actual level circuit and the instrument had a large (unknown) collimation error, the sightline distances were unbalanced, but the sightline distances were inverted for the second instrument setup, the closure error criterion for a valid level circuit would have indicated a problem with the circuit. By inverting the sightline distances in a circuit that has unbalanced sightline distances, unknown collimation errors of an instrument can be reflected in the closure error. If the location of objective points and the locations for setting up the instrument cause unbalanced sightline distances to be unavoidable, it is recommended that these distances be inverted so that the object that was farthest from the first instrument setup becomes closest to the second instrument setup. The technique of inverting the sightline distances is designed to expose any unknown instrument error in the circuit closure error, thus alerting the user of possible systematic instrument error.

Leveling Rods

Many kinds of leveling rods are available for use in running levels at gaging stations. Rods come in different lengths, many are expandable, and they are made of different materials. Many rods, such as the “Philadelphia” or “Chicago” style rods, are made of a structural material, often wood or fiberglass, and a rod-scale material, such as Invar or steel. Invar is a nickel steel alloy, commonly used for precise measuring equipment and has a very low coefficient of thermal expansion (CTE). Self-reading rods with numeric scales ([fig. 7](#)) are used with optical engineer’s levels, while electronic digital levels use leveling rods with bar-code scales ([fig. 4](#)). The scales of self-reading rods are typically divided into feet and tenths and hundredths of feet by means of alternating black and white spaces (McCormac, 1983) ([fig. 8](#)). Bar-code leveling rods often have a self-reading scale on the second side of the rod to use with the optical system of the instrument ([fig. 4A](#)). For gaging-station levels, self-reading rods must be graduated to 0.01 ft and readings are visually interpolated in order to meet the measurement-precision requirement of 0.001 ft. Regardless of the type of engineer’s level, when running levels at gaging stations, it is good practice to not extend a rod more than about 16 ft because of the difficulty in holding a tall rod steady and level on an objective point. A leveling rod should always be used in conjunction with a rod level.

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Table 3. Notes for gaging station levels run when sightline distances between the instrument and objects vary inversely for two setups and the instrument used has a collimation error of 0.01 foot per 100 feet.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. BS, backsight; HI, height of instrument; FS, foresight; RM, reference mark; TP, turning point; NA, not applicable]

Object	Distance from instrument to object	BS error ¹	BS	HI	FS error ¹	FS	Elevation	Closure error	True elevations	Difference from true elevation
RM1 (origin)	200	0.020	5.270	105.270	0.020	NA	² 100.000	NA	100.000	NA
RM2	150	NA	NA	NA	0.015	7.126	98.144	NA	98.139	0.005
RM3	100	NA	NA	NA	0.010	2.042	103.228	NA	103.218	0.010
TP	10	NA	NA	NA	0.001	3.334	101.936	NA	101.917	0.019
Instrument moved and re-leveled										
TP	200	0.020	4.353	106.289	0.020	NA	101.936	NA	101.917	0.019
RM3	150	NA	NA	NA	0.015	3.047	103.242	NA	103.218	0.024
RM2	100	NA	NA	NA	0.010	8.121	98.168	NA	98.139	0.029
RM1	10	NA	NA	NA	0.001	6.251	100.038	-0.038	100.000	0.038

¹ Computed from the collimation error and the distance from the instrument to the object.

² Given elevation in the level circuit.

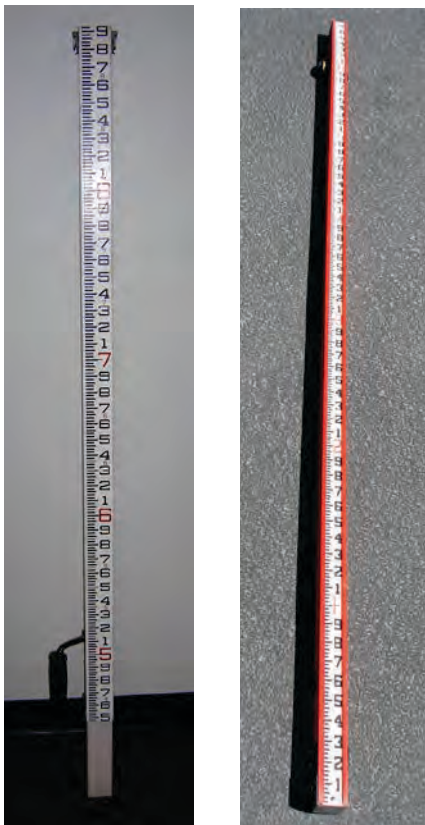


Figure 7. Self-reading leveling rods.

Inspection of Leveling rod

Leveling rods should be examined regularly to ensure that their scales are set correctly and that their structure, specifically the bottom surface, is free of damage or debris. If a leveling rod is found to be damaged it should be removed from service. Thermal expansion or contraction of the material of the rod scale should be considered when the rod is used for gaging-station levels. The most common materials for leveling-rod scales include Invar, fiberglass, steel, and wood. Most rod scales are calibrated at the standard temperature of 68°F. The entire scale length for a self-reading rod should be verified with an independent measuring tape from the bottom of the rod. Similar independent verification checks of all other measuring devices used when running levels should also be done. All verifications should be made indoors at the standard temperature of 68°F. Rods should be checked with a measuring tape at each foot marking along the length of the scale and at both sides of any joints between scale sections. If all graduations are accurate to within |0.002| ft, the rod is satisfactory (Kennedy, 1990). If a rod scale is found to be outside of the |0.002|-ft tolerance, adjust the scale if possible or remove the leveling rod from service. At temperatures greater than the calibration or standard temperature, the rod scale will expand causing measurements to be lower than they actually are, and at temperatures less than the calibration temperature, contraction of the rod scale will have the opposite effect. To minimize both errors in shots taken to leveling rods, and the need to apply corrections to measurements due to thermal expansion or contraction, it is recommended that leveling rods (including all devices used as rods during level

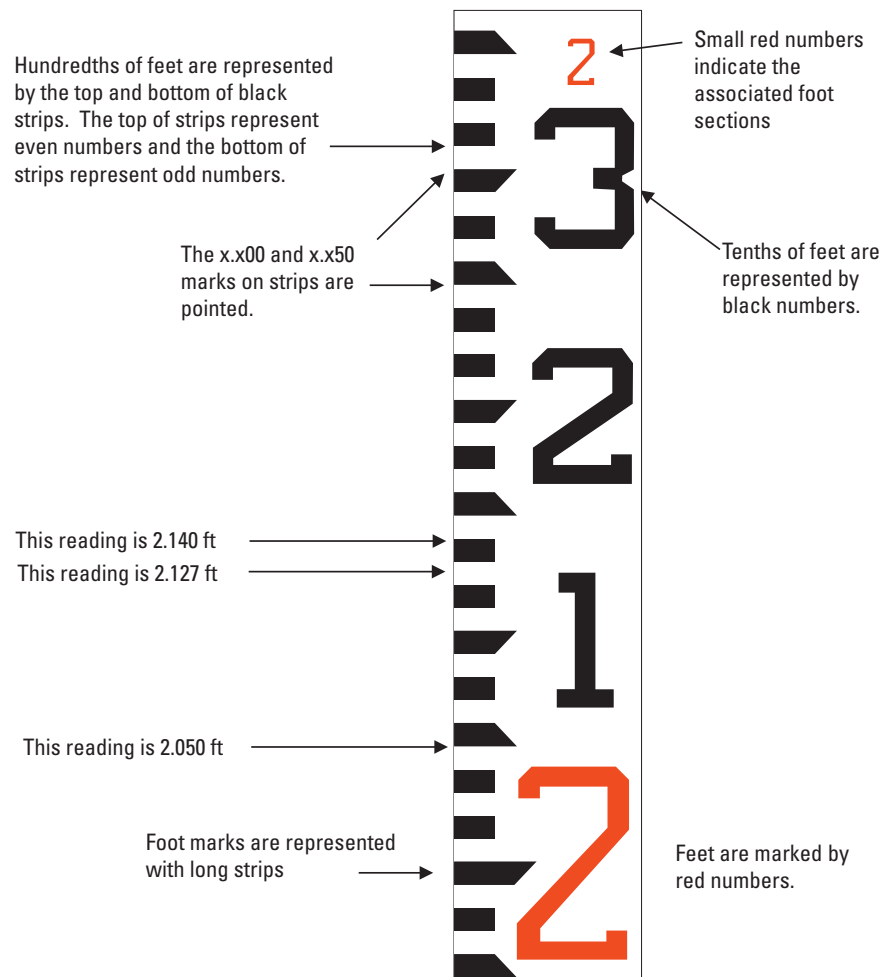


Figure 8. Scale of a self-reading Philadelphia rod.

runs) be used at temperatures near the calibration temperature of the rod scale whenever possible. Determining the need for and computing temperature corrections is discussed in the section on [“Correcting for Rod Scale Expansion or Contraction Due to Temperature Variations.”](#)

Proper Care and Use of a Rod Level

It is important that the leveling rod be held vertical when levels are run at gaging stations. To ensure that the leveling rod is vertical, a rod level should always be used. Rod levels are either stand alone ([fig. 9A](#)) and are used with multiple leveling rods, or permanently attached and dedicated to a single leveling rod ([fig. 9B](#)). The stand-alone rod levels consist of a bull’s eye bubble level mounted on a 90-degree or square channel material. The 90-degree channel allows the rod level to be held along the vertical axis of either a square or round leveling rod. Rod levels should be checked for plumb regularly and adjusted if necessary. To test the rod level, any corner such as a wall corner that has been verified to be level

using a carpenter’s level can be used. Most rod levels have screws that are used to adjust how the bubble level is seated in its mount. When checking for plumb, the bubble should be examined for expansion. If the bubble has expanded beyond the circular level indicator line, the rod level should be discarded.

Correcting for Rod Scale Expansion or Contraction Due to Temperature Variations

At constant temperatures, measurements can be precisely corrected for expansion and contraction of the rod-scale material due to temperature variation. All materials have a determined coefficient of thermal expansion (CTE), and the CTE for the rod scale should be readily available from the manufacturer of the rod. Material compositions of rod scales vary, particularly for fiberglass rods; therefore, it is recommended that the rod scale CTE be obtained directly from the manufacturer. For reference, CTE ranges for some common leveling rod-scale materials are provided in [table 4](#).

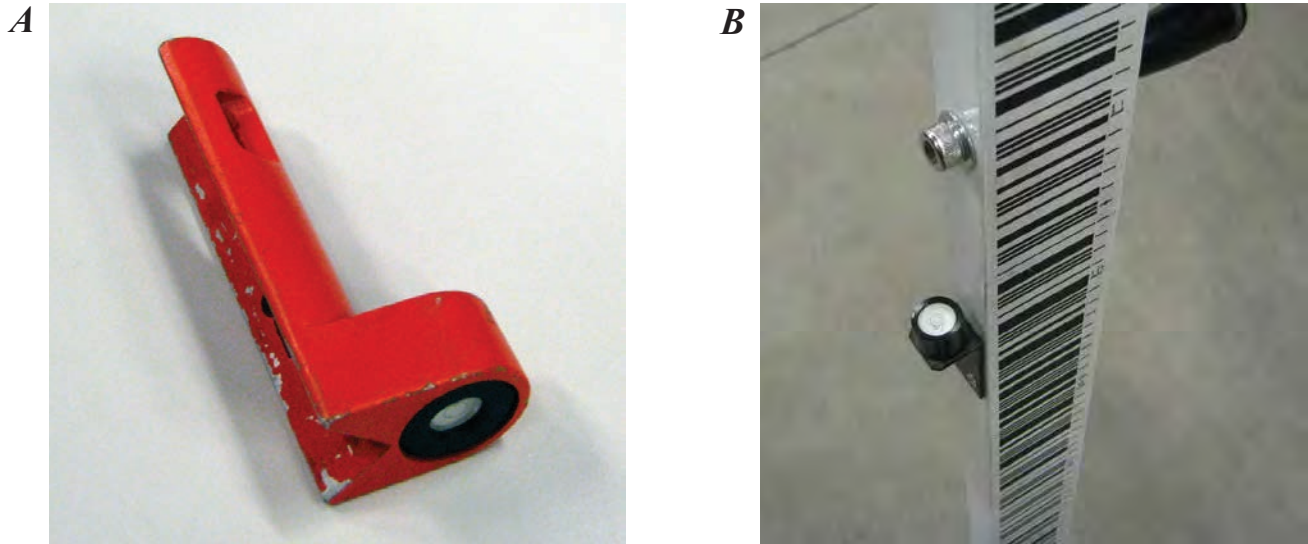


Figure 9. Stand-alone *A.* and permanently attached *B.* rod levels.

The rod-scale material-specific CTE, the standard temperature, and the rod-scale temperature at the time the leveling rod is used for a measurement are used in the following equation to determine the correction for expansion or contraction due to temperature variation:

$$C_t = \text{CTE} * L(T - T_o), \quad (3)$$

where

- C_t is the correction for expansion or contraction due to temperature variation, in unit length,
- CTE is the rod – scale material – specific coefficient of thermal expansion, in 1/ degrees Fahrenheit or 1/ degrees Celsius (examples contained in table 4),
- L is the length of the measurement, in unit length,
- T is the rod – scale temperature at the time of the measurement, in degrees Fahrenheit or degrees Celsius, and
- T_o is the standard temperature, in degrees Fahrenheit (usually 68°F) or degrees Celsius (usually 20°C).

The rod-scale temperature, T , can be measured directly by an infrared thermistor, or if the rod is not in the direct sun, air temperature can be used as a surrogate for the rod temperature. To determine whether corrections are needed for a given level circuit, first compute or estimate the maximum elevation

difference between the origin reference mark and any point in the level circuit. This is the difference between the elevation of the origin and either the highest or the lowest point that a FS will be taken on. Substitute this difference for L in equation 3 and compute C_t . If the absolute value of C_t is greater than 0.003, all FSs and BSs of the circuit should be corrected for temperature-related expansion or contraction. Individual FSs and BSs taken during a level run can be corrected by adding the rod reading to the computed expansion or contraction correction value by using the equation

$$S_{\text{corrected}} = S_{\text{read}} + (\text{CTE} * S_{\text{read}}(T - T_o)), \quad (4)$$

where

- $S_{\text{corrected}}$ is the sight (backsight or foresight) corrected for expansion or contraction due to temperature variation, in unit length,
- S_{read} is the sight (backsight or foresight) obtained from the leveling rod, in unit length,
- CTE is the rod-scale material-specific coefficient of thermal expansion, in 1/degrees Fahrenheit or 1/degrees Celsius (examples contained in table 4),
- T is the rod-scale temperature at the time of the measurement, in degrees Fahrenheit or degrees Celsius, and
- T_o is the standard temperature, in degrees Fahrenheit (usually 68°F) or degrees Celsius (usually 20°C).

Table 4. Approximate coefficients of thermal expansion for common leveling rod-scale materials.

Rod-scale material	Approximate coefficient of thermal expansion	
	in length/length/degree Fahrenheit (1/°F)	in length/length/degree Celsius (1/°C)
Invar ¹	0.8×10^{-6}	1.4×10^{-6}
Wood ¹	2.1×10^{-6} to 2.8×10^{-6}	3.8×10^{-6} to 5×10^{-6}
Steel tape ²	6.45×10^{-6}	12×10^{-6}
Fiberglass ¹	17×10^{-6} to 22×10^{-6}	30.6×10^{-6} to 39.6×10^{-6}

¹ From http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html.

² From Breed, Hosmer, and Bone (1970).

Considerations for Secondary Devices Used for Vertical Measurements

When running levels at gaging stations, a secondary measuring device other than a leveling rod might be required to take FSs on gages or to carry elevations over a large vertical distance. The CTE for the materials that compose secondary devices used in a level circuit should be obtained and used to correct FSs and BSs when appropriate. Any secondary devices used must meet the precision and accuracy requirements of gaging-station levels. When using a measuring tape to carry elevations between a bridge deck and a low water bank, the tape should be weighted so that the tape is not stretched and the tension applied by the weight should ensure that the tape is suspended vertically. [Figure 10](#) is a photograph of a steel tape with a 1-pound weight that is commonly used for measuring water levels in wells. This same equipment can be used for tape-down measurements or for carrying elevations over a large vertical distance. The practical limit of measurement precision for this tape-down method is ± 0.01 ft (U.S. Geological Survey, 1980). If used when running levels at gaging stations to carry elevations between a bridge deck and a low water bank, the FSs or BSs should be estimated to 0.001 ft.

Wind can have a profound effect on suspended measuring devices, particularly those suspended from a bridge. Wind will cause a suspended tape to bend and artificially increase the vertical distance the tape is spanning. Wind effects cannot be accounted for, so vertical measurements using a suspended measuring tape affected by wind should be avoided.



Figure 10. Steel tape with 1 pound of tension.

Establishment of Gage Datum

The gage datum is the reference surface at a gaging station to which all gages are set (Corbett and others, 1943) ([fig. 11](#)). The reference surface is represented by the 0.000-ft mark on the gages and should be located well below the streambed, below any likely gage height of zero flow (GZF). The gage datum is usually an arbitrary reference but it can be tied to an established datum, such as the North American Vertical Datum of 1988 (NAVD 88), through the use of established benchmarks. When a gaging station is being established where no station has existed previously, the gage datum should be set low enough to ensure that the lowest gage height ever likely to be recorded while the stream is flowing is at least 1 ft (Kennedy, 1990). When establishing the gage datum, the current water depth over the hydraulic control of the gage pool should be known and the potential maximum streambed scour should be considered. Experience with stream channels of similar materials, geometry, and basin characteristics may provide some indication of the potential magnitude of streambed scour. Because negative gage heights are undesirable, the gage datum reference surface that is selected should be well below the estimated maximum scour depth to avoid negative gage heights over the life of the station.

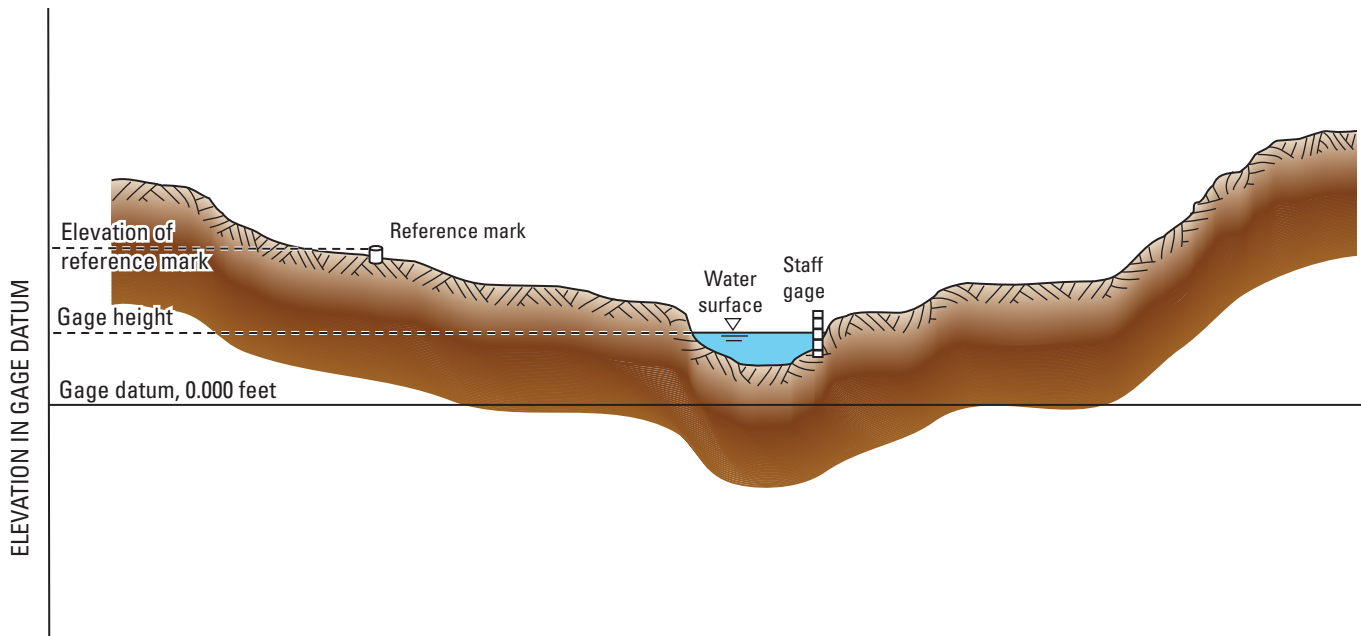


Figure 11. Gage datum at a station.

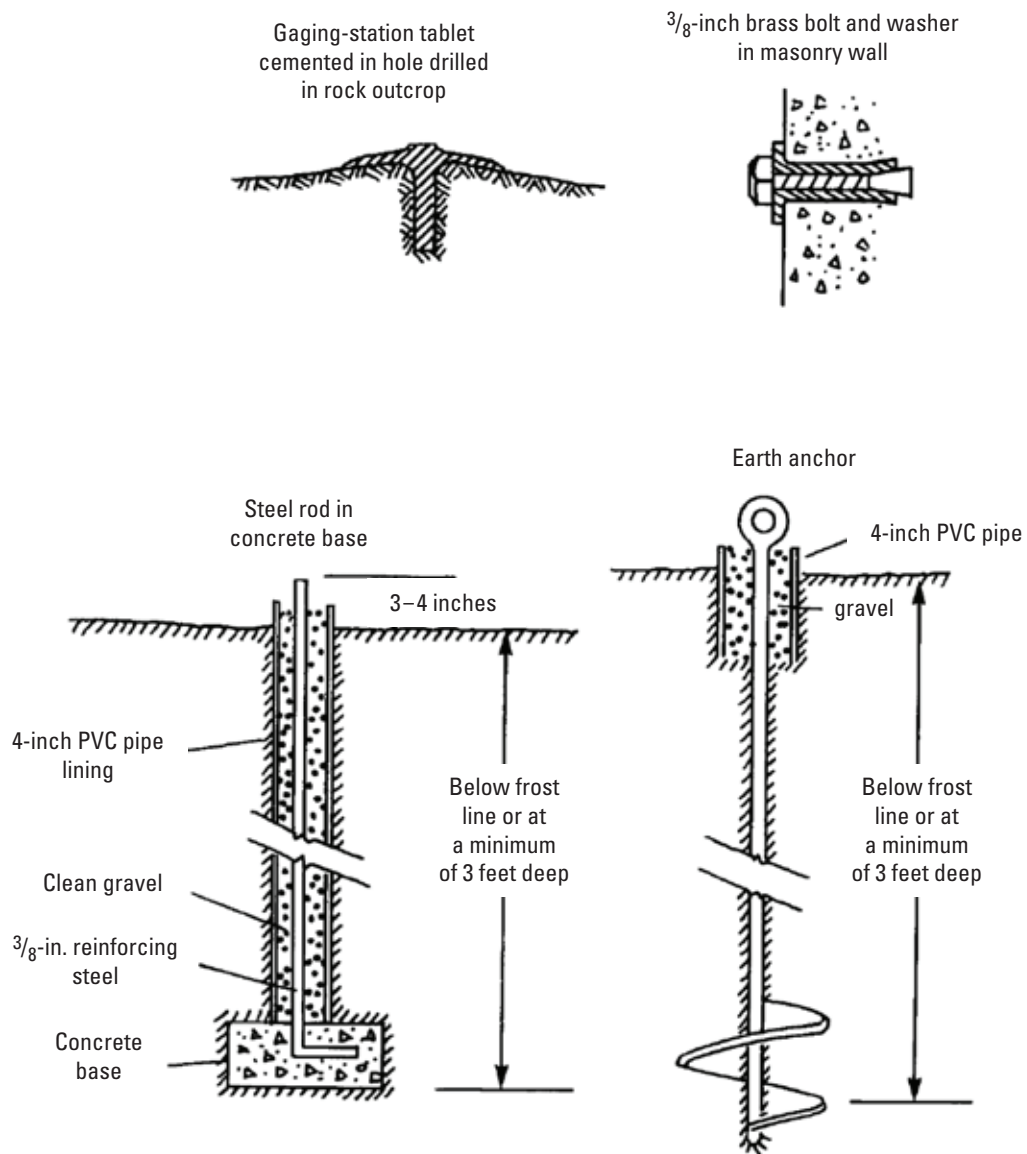
Installation of Reference Marks

Reference marks are installed and elevations are determined in the gage datum when gaging stations are established. Stable and permanent reference marks facilitate maintaining that the gages at a station are set to the gage datum over the life of the station. Typical reference marks include gaging-station tablets cemented and drilled into rock outcrops, bolts drilled into masonry walls, steel rods driven and cemented into stable ground, and other earth anchors located below frost lines ([fig. 12](#)). Reference marks provide a means for recovering the gage datum if the gaging station is destroyed or is removed and reactivated sometime later. The most stable locations for reference marks are often rock outcrops and substantial masonry structures. Bridges often provide a stable environment for reference marks; however, bridges that sway or have a high traffic volume may not be desirable because precise measurements are difficult to make with a level and rod. In the absence of rock outcrops and stable masonry structures, reference marks can be anchored at depths below the local frost depth in stable soils ([fig. 13](#)). The methods used by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, and National Ocean Survey for establishing geodetic benchmarks (Floyd, 1978) can provide guidance for installing reference marks. Clay soils that expand and contract during seasonal variations in soil moisture should be avoided (Kennedy, 1990).

Gaging stations should have a minimum of three independent reference marks; more than three are recommended whenever possible in case one (or more)

proves to be unstable or is destroyed. These marks should be located independently of one another. For example, if one or more reference marks are installed on a bridge structure, at least two others should be installed somewhere away from (and independent of) the bridge. Furthermore, reference marks should be located independently of any gage, gage infrastructure, or instream control structure, because reference marks are used to track vertical changes over time to the gages and to the other marks. If reference marks and gages are not independent of one another, determining vertical differences becomes difficult.

When locating reference marks, other considerations should be made. Access to reference marks during flood conditions is important to verify that the recorder is accurately set to the gage datum in case the reference gage is inaccessible. Ideally, at least one reference mark should be located outside of the floodplain. When determining the locations of reference marks, running levels should be considered and, if possible, marks should be located so that sightline distances are balanced and levels can be run in an efficient manner. The potential for damage or destruction of reference marks related to construction, specifically road construction or future land development, should be considered. Finally, reference marks should be easily found from descriptive statements in the station description document. As discussed later, site sketches showing the location of reference marks should be prepared. If vegetation is likely to obscure marks over time, exact measurements from local objects should be provided and a witness post should be installed.



Modified from Kennedy (1990).

Figure 12. Typical reference marks.

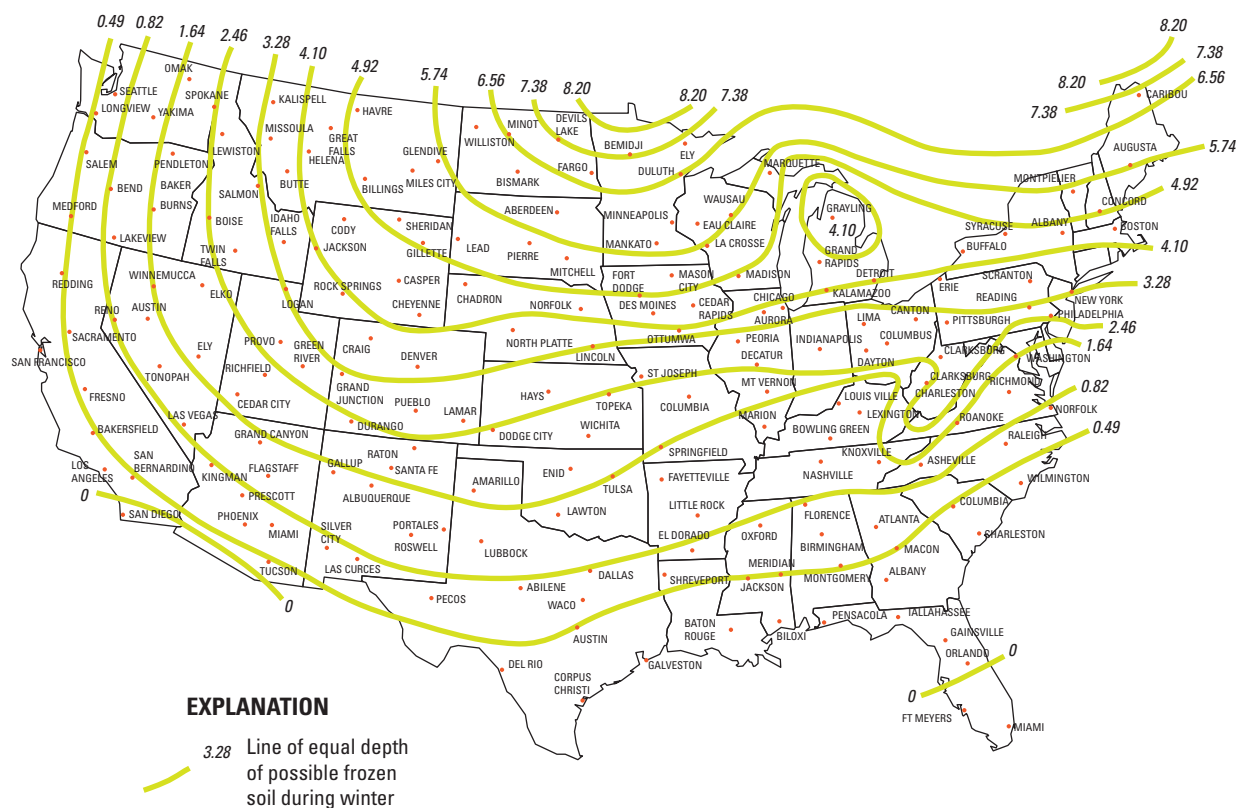


Figure 13. Extreme depth of frost map.

Referencing a Gage Datum to an Established Datum

It is desirable to reference an arbitrary gage datum to a commonly used established datum, such as NAVD 88, at all gaging stations. This is especially important at stations used by the National Weather Service for flood forecasting or at locations where flood profiles are likely to be needed (Kennedy, 1990). Generally, two methods are used to tie a gage datum to an established datum - running a traditional survey line and using a survey grade Global Positioning System (GPS).

The first method is to run a traditional survey line consisting of a closed level circuit or a series of closed level circuits from an established survey control point to the origin or base reference mark of a gaging station. The National Geodetic Survey (NGS) maintains a database of established and maintained survey control points or benchmarks throughout the United States that are available at <http://www.ngs.noaa.gov/cgi-bin/datasheet.prl>. This database can be used to find the location of the nearest control point and its elevation in NAVD 88. The distance between the gaging station and an established survey control point may be considerable and therefore the survey line will consist of a number of different instrument setups and turning points. Techniques for running survey lines from

established benchmarks outlined by the National Oceanic and Atmospheric Administration (Schomaker and Berry, 1981) should be used to tie gage datums to established datums.

The second method is to use a survey-grade GPS to determine the elevation of a gaging station reference mark above an established datum. Usually, the GPS is set up over the reference mark of interest and allowed to collect positional data over a set time interval. The uncertainty of the positional data decreases with increased occupation time over the reference mark. GPS technology and therefore the recommended methods for collecting positional data using a GPS, is continually changing. Follow currently accepted agency guidelines and methods for determining elevations with a survey-grade GPS.

After determining the elevation of a gaging station reference mark above an established datum, the gage datum can then be referenced, or tied, to the already established datum. The gage datum is the 0.000 ft reference surface at a gaging station. To determine the elevation of this surface above the desired established datum, subtract the elevation of the reference mark above the gage datum from the elevation for the same reference mark above the established datum. All other reference marks, reference points, and gages can then be assigned elevations above the established datum by adding the elevation of the gage datum above the established datum to their elevation above the gage datum.

Frequency of Gaging-Station Levels

Gaging-station locations and environments vary widely as do the factors affecting the stability of reference marks and gages. The relative stability of a gaging station needs to be considered when determining the frequency at which levels should be run. For example, a station affected by ground

freezing and thawing may require levels to be run annually in the spring, while a station with gages and reference marks fixed to bedrock that has demonstrated stability may require levels to be run only every 5 years. Gaging-station levels should be run frequently enough to capture any gage movement that may occur. A decision tree is provided ([fig. 14](#)) to help determine when levels need to be run at a gaging station.

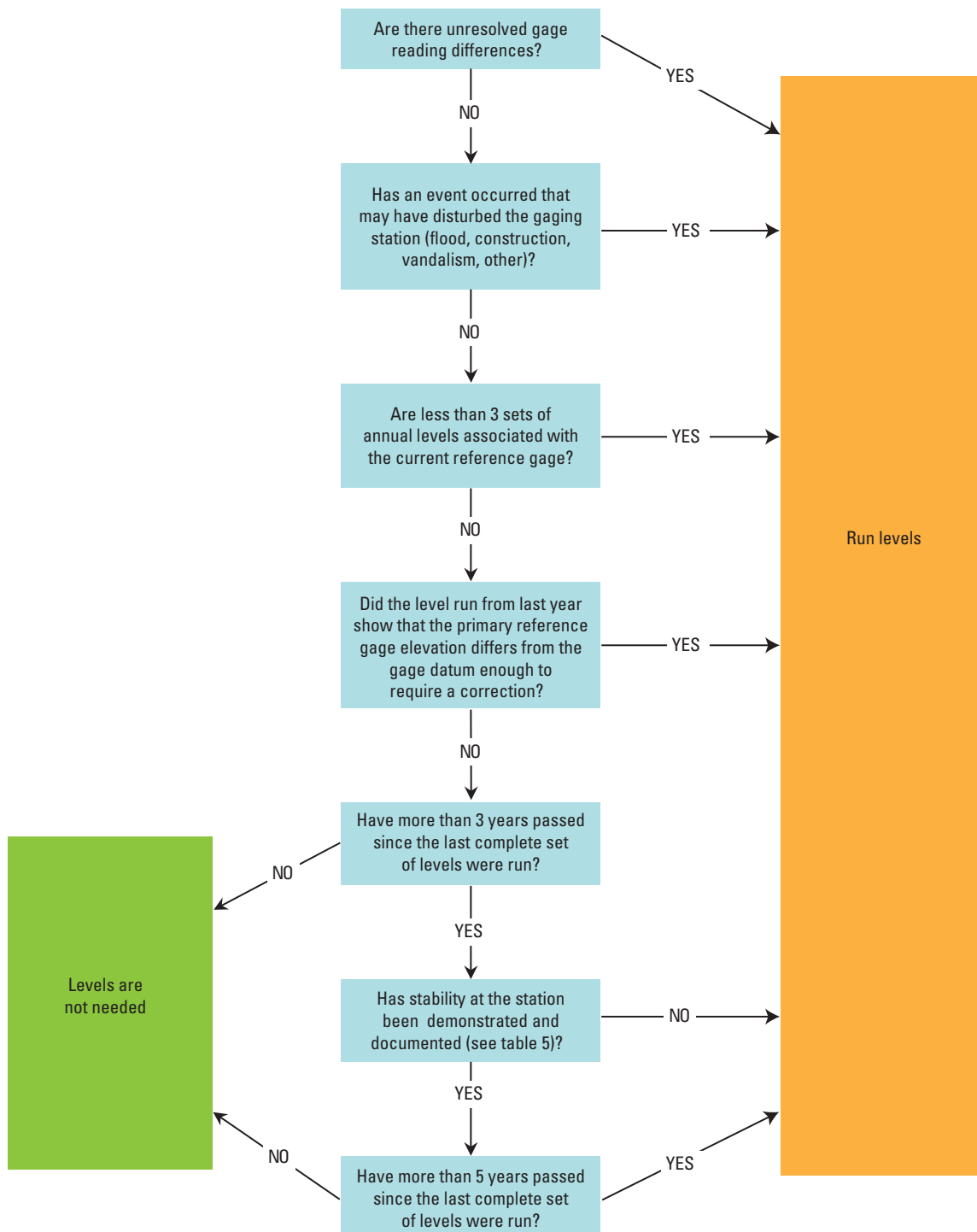


Figure 14. Decision tree for determining if levels are needed.

In addition to running levels according to the site-specific determined frequency, levels should be run whenever a difference in gage readings cannot be resolved or damage is suspected. Suspected damage to a gage may be associated with flooding, ice, vandalism, nearby construction, or other events that may disturb some part of the gaging station. A new gage installation (including the installation of a new reference gage at an existing station) should have three sets of annual levels, including the initial establishment set, acquired during the first 3 years of operation. After the first three sets of levels are acquired, a level frequency of once every 3 years may be adopted. A level frequency of at least every 5 years may be adopted if stability is shown to exist. Stability is demonstrated if the maximum elevation difference from the initial elevations for the primary reference gage and three reference marks is less than |0.015| ft for a minimum of five sets of levels and a period of at least 10 years (table 5). This means that for any set of levels run during a 10-year period, the elevations for the primary reference gage and the three reference marks (these must be the same three marks measured over the minimum five consecutive sets of levels) cannot differ from the initial elevation (as determined at the beginning of that 10-year period) by |0.015| ft or more. If elevations for any of these four objective points change by |0.015| ft or more, the site is not considered stable and the frequency that levels are run cannot exceed 3 years. An example of a summary of levels for a station where the stability criterion was not met

Table 5. Requirements for demonstrating gaging station stability.

Minimum years that a reference gage and three reference marks have been active	10
Minimum number of sets of levels	5
Maximum difference in elevation from the initial elevation (as determined at the beginning of a 10-year time period), in feet, of a reference gage and three reference marks	< 0.015

Table 6. Example summary of levels where the stability criterion is not met.

[All values are given in feet. Elevations are referenced to an arbitrary gage datum. RM, reference mark; adj., adjustment; NA, not applicable; ft, foot]

Date	Elevations						Differences in elevation			Remarks
	RM1 (given)	RM2	RM3	Reference gage			RM1 (given)	RM2	RM3	
				Water surface found	Water surface left	Adj. made				
04/01/1999	12.525	8.623	10.226	4.234	4.234	NA	NA	NA	NA	
04/14/2000	12.525	8.621	10.228	4.325	4.325	0	0	−0.002	0.002	
03/28/2001	12.525	8.622	10.224	3.999	3.999	0	0	−0.001	−0.002	
04/02/2004	12.525	8.635	10.242	4.177	4.177	0	0	0.012	0.016	RM3 different by 0.016 ft
04/15/2007	12.525	8.635	10.240	4.440	4.440	0	0	0.012	0.014	
04/02/2010	12.525	8.635	10.244	4.013	4.013	0	0	0.012	0.018	RM3 different by 0.018 ft

is shown in table 6. If during any level run, regardless of the determined frequency of levels, the elevation of the primary reference gage differs from the gage datum by |0.015| ft or more (requiring the gage to be reset and the recorded and (or) observed stage values to be corrected), levels must be run again the following year. If no correction is required the following year, the level frequency can be reset to a 3-year cycle, until stability can be demonstrated.

Preparation for Running Levels

Running levels at gaging stations is important for accurate measurements of stage and subsequent computation of streamflow over the life of the station. Uncertainties related to measurement error during the leveling process can be minimized if adequate preparations are made. Equipment should be properly tested and calibrated, and site-specific information important to the leveling process should be gathered. Crews assigned to run levels should be properly trained in the procedures explained in this manual and be familiar with the equipment they will be using. Levels should be run in favorable weather conditions and site-specific environmental conditions; safety hazards that may be encountered should be understood and discussed before traveling to the site.

Determining the Need for Levels

The first step in preparing to run levels is to determine whether or not levels are needed at a specific gaging station. The need for levels should be assessed using the decision tree (fig. 14) at least once a year for each station and more frequently if differences in gage readings cannot be resolved or damage to the gage is suspected. Offices are encouraged to implement a tracking system to determine when levels are due to be run at each of their stations. It is beneficial operationally

for an office to schedule level runs for about one-third of its stations each year. This will ensure that the leveling workload in an office is balanced and will allow additional stations that have an immediate need for levels to be run to be more readily incorporated. The time of year that levels are run at stations should follow the likely factors that cause changes to the reference gage. For example, if stations are susceptible to frost heave, it is best to run levels as soon as possible after the spring thaw, ideally at temperatures near the standard temperature of the leveling rod-scale material (usually 68°F).

Compiling Historic Level Notes and Site Sketch Maps

Past level notes for the station where levels are to be run should be reviewed. These notes show the previous composition of the level circuit(s), which can assist in planning the new level circuit(s). The past level notes can be used to determine the maximum elevation difference between the origin and any point in the circuit (L in equation 3). This information is needed to determine whether or not the leveling-rod scale must be corrected for expansion or contraction. The historic level summary should be examined for any stability issues related to reference marks and reference points. Finally, copies of the past set of level notes and the site sketch map should be made and taken to the site.

Considerations for Site Conditions

The expected environmental conditions at the site where levels are to be run should be considered. The river stage should be amenable to determining accurate water-surface elevations from the low water bank and taking FSs to all reference marks, reference points, and gages. Levels should be run in favorable weather conditions; wind, rain, and snow should be avoided if at all possible. Air temperature and its affect on leveling-rod scales needs to be considered. Vegetation located in sightlines is undesirable and may be avoided through maintenance or running levels during times when leaves are off trees and shrubs. The survey crew should be briefed on all safety hazards specific to the site where the levels are to be run. These hazards should be documented and available in the site-specific job hazard analysis document.

Running Levels

After determining that levels are needed at a gaging station and making the necessary preparations, levels should be run following the procedures outlined below. Ideally, the leveling instrument should be set up in a location that allows for balanced sightline distances to the objects to be shot from this instrument setup. The instrument should be placed upon a firmly set tripod in a stable location at a height that allows

for a comfortable position for the instrument operator and accurate readings of the rod on the objects to be shot. The instrument should be properly leveled using the leveling tools of the instrument. Before beginning the level run, the time should be noted and all of the gages and recorders at the station should be read. The temperature of the leveling rod should be equilibrated to the air temperature. Rod-scale and air temperatures should be measured and noted. The rod-scale temperature can be measured directly using an infrared thermistor, or if the rod is not in the direct sun, air temperature can be used for the rod-scale temperature. Equation 3 should be used to determine the maximum expansion or contraction correction for the level circuit. For this determination, L in equation 3 should be set equal to the maximum elevation difference expected between the origin and either the highest or the lowest point to be surveyed. If the absolute value of the correction for expansion or contraction due to temperature variation is greater than 0.003 ft, all FSs and BSs of the level circuit should be corrected using equation 4.

To describe the procedures for running levels at a gaging station, a very simple level circuit with two instrument setups is presented here. Determine the order in which the reference marks, reference points, gages, water surface, and other objects are to be shot. The initial instrument height is determined from a BS to the origin, as determined from historical levels at the station. The BS value, measured to the nearest 0.001 ft, should be corrected for expansion or contraction of the rod scale if needed and then added to the given elevation of the origin reference mark to obtain the instrument height. Foresights read to the nearest 0.001 ft should then be taken to the reference marks, reference points, gages, water surface, and other objects that were planned to be shot from the current instrument setup. If appropriate, FSs should be corrected for temperature-related expansion or contraction of the rod scale. The corrected FS values should be subtracted from the corresponding instrument height to obtain elevations in the gage datum. All gages and recorders should be read and noted with corresponding times just before or immediately after the FS on the water surface.

After taking a FS on all objective points that were planned to be shot from the current instrument setup, a turning point should be established. The turning point should be a stable, independent object that is not an objective point of the level circuit. This point will be used to establish a new instrument height from which second elevations will be determined for the objects previously shot. Take a FS on the turning point, and if necessary, correct for expansion or contraction, and then determine its elevation. Following this FS, the instrument should be moved and re-leveled in a location that again balances the distances to the objective points. However, if the sightline distances to the objective points were unbalanced in the initial instrument location, the new instrument location should invert the sightline distances by being set up closer to the objective point that was farthest from the initial setup. Take a BS to the turning point, and if required, correct for expansion or contraction of the rod scale

and add it to the determined elevation of the turning point to determine a new instrument height. From this new instrument height, take FSs to the same objective points, correcting for expansion or contraction if conditions require it, and obtain second elevations for each. To close the leveling circuit, the final shot should be a FS taken on the origin reference mark that, if necessary, should be corrected for expansion or contraction of the rod scale.

If a FS on the water surface cannot be taken directly using the leveling rod, a measurement using a measuring tape may be made from a reference point from which two FSs were taken. The length of the tape up or down measurement should be as short as possible by measuring from a temporary or permanent reference point on the low water bank from which two FSs were taken. Tape downs from a bridge or similar structure should not be used to obtain the water-surface elevation during a level run.

The procedure presented above describes a simple gaging station level circuit in which all FSs to objective points can be taken from a single instrument setup. To help illustrate the procedures for running levels at gaging stations, a complete set of level notes from a level circuit that required only two instrument setups is shown in [figure 15](#). The turning point that was used to determine the second instrument height was not an objective point of the circuit. In order to ensure that two FSs were taken on each objective point of the circuit, an independent turning point was required. If an objective point was used as the turning point in this circuit, that objective point would not have two FSs taken from two different instrument heights from which elevations could be compared.

Quite often, level circuits are more complex than the one presented above and require multiple instrument setups, and thus more than one turning point, to be able to take two FSs on all objective points. Intermediate turning points, those used to carry elevations to different instrument setup locations on either the “out” or the “back” parts of the level circuit, can be objective points if, when the circuit is completed, they have two FSs taken on them. Because these objective points are being used as turning points, they will also have at least one BS taken on them as well. However, regardless of circuit complexity, the turning point ascertained after determining all first elevations and before determining second elevations must be independent (not one of the objective points). This independent turning point marks the termination of the out part and the beginning of the back part of the level circuit, or loop. To help illustrate the procedures for running levels at gaging stations using multiple turning points, a complete set of level notes from a level circuit that required eight instrument setups is provided in [figure 16](#). A level notes form, available for printing and downloading, is provided in [appendix C](#).

Standards and Requirements for Gaging-Station Levels

Three orders of vertical control classification are accepted by the Federal Geodetic Control Committee (1984). In this classification scheme, first- and second-order leveling can be applied to the vertical control for National geodetic surveys, and second- and third-order leveling can be applied to engineering projects of varying size and scope. Selected requirements associated with the three classifications that are pertinent to gaging-station levels are presented in [table 7](#). Gaging-station levels generally are classified as third-order levels with the adoption of some first- and second-order requirements. [Table 8](#) shows adopted standards and requirements for gaging-station levels.

Circuit-Closure Error

The closure error of a leveling circuit is the difference between the given elevation for the origin reference mark and the elevation for that reference mark associated with the final instrument height of the level circuit. Closure error is computed as the given elevation minus the final elevation. Assigned vertical closure-error limits define the desired and acceptable accuracy, or error, for the intended use of the survey data. The random acquisition of error in a level circuit tends to vary with the square root of the number of opportunities or instrument setups (Davis and others, 1966). Therefore, a vertical closure-error limit for differential levels can be determined by multiplying an acceptable uncertainty constant by the square root of the total number of setups. This acceptable uncertainty depends on how the data will be used and should be amenable to the desired accuracy and precision requirements of the levels. For gaging-station levels, the uncertainty constant is 0.003 ft (Kennedy, 1990). The vertical closure-error limit for gaging station level circuits is computed using the equation

$$CE_{\text{limit}} = 0.003\sqrt{n}, \quad (5)$$

where

CE_{limit} is the closure-error limit, in feet, and
 n is the total number of instrument setups in a level circuit.

PEG TEST OF ENGINEER'S LEVEL			
Make/Model:	System type(s) circle: <u>optical</u>	digital	
$\text{Collimation} = c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right]$			
Average of d_2 and d_4 should be less than 110 ft			
OPTICAL SYSTEM		R	d
$c = 100 * \left[\frac{((4.930 + 5.415) - (5.772 + 4.572))}{((137.5 + 73.5) - (10 + 74))} \right]$		1	4.930 10
		2	5.772 137.5
		3	5.415 74
		4	4.572 73.5
DIGITAL SYSTEM		R	d
$c = 100 * \left[\frac{((\quad + \quad) - (\quad + \quad))}{((\quad + \quad) - (\quad + \quad))} \right]$		1	
		2	
		3	
		4	
c = _____ ft/100ft as found			
ADJUSTMENT (level remains set up at 2 and sighted at R_4)			
Adjust cross hair to: $R_1 \pm \left[\frac{(cd_1)}{100} \right] = \pm \left[\frac{(\quad)}{100} \right]$ Repeat collimation test after adjustment			
CLOSURE ERROR COMPUTATIONS		NOTES or SKETCHES:	
Circuit No.	No. of Inst. Setups (N)	Allowable closure Error (CE) (N) ^{1.5}	CE/N (take to 0.0001)
1	2	0.0042	-0.0015

Figure 15. Complete set of level notes for a level circuit with two instrument setups.

U.S. DEPARTMENT OF THE INTERIOR U.S. Geological Survey Gaging Station Level Notes			
Station Number:	Station Name		
09285900	Strawberry River at Pinnacles near Fruitland, Utah		
Date	Party	(inst.)	(rod)
April 20, 2009	MLF	RJE	
SUMMARY OF OBJECTIVE POINTS			INSTRUMENT
Object	Adj. 1st Elev.	Diff. (1st Elev. - 2nd Elev.)	Final Elev. (Ave. of Adj. Elev.)
RM2	Given		4.160
RM1	2.788	0.003	2.786
RM4	6.200	6.197	6.198
CSG	3.820	-0.001	3.820
OG	2.552	0.004	2.550
			ROD
Scale material <u>Invar</u> CTE <u>0.8*10^-6</u> <u>1/F</u> or 1/C°			
CTE conversions: (1°F * 1.8 = 1°C) and ((1/°C)/(1.8 = 1°F)			
Temperature (T): Rod: <u>75.6°F</u> or °C; Air: <u>75.6°F</u> or °C			
Standard temp (T ₀): <u>68°F</u> or 20°C or other: _____			
Given/Origin elevation: <u>4.160</u>			
Max elevation of objective point: <u>6.200</u>			
Min elevation of objective point: <u>1.520</u>			
Max elevation difference (L): <u>3.157</u>			
C _t = CTE * L(T - T ₀) C _t = <u>-0.0001</u>			
Other devices used as rod (list): <u>none</u>			
GAGE READINGS			
Time	WS	Ref. OG	Ref. DCP
13:05			1.52
13:15	1.517		1.52
13:25	1.515		1.52
13:30			1.52
GAGE RESET			
		Ref. OG	DCP
		1.52	1.52
		Found	Left
		1.52	1.52
WEATHER: <u>Clear, sunny, warm</u>			
NOTES: <u>No changes needed or made.</u>			
Computed by: <u>MLF</u> Checked by: <u>RJE</u> Date: <u>April 22, 2009</u>			

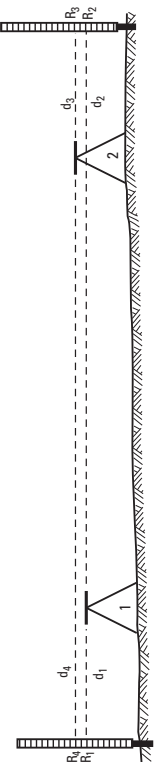
PEG TEST OF ENGINEER'S LEVEL									
Make/Model:		System type(s) circle: optical digital							
									
$\text{Collimation} = c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right]$									
Average of d ₂ and d ₄ should be less than 110 ft									
OPTICAL SYSTEM									
			R	d					
c = 100 *	[(4.834 + 4.715) - (2.643 + 6.901)]	[(109.4 + 108.9) - (9.6 + 10.2)]	ft/100ft as found	1	4.834	9.6			
				2	2.643	109.4			
				3	4.715	10.2			
				4	6.901	108.9			
DIGITAL SYSTEM									
c = 100 *	[(4.940 + 4.559) - (2.748 + 6.747)]	[(109.1 + 108.7) - (9.9 + 10.2)]	ft/100ft as found	1	4.940	9.9			
				2	2.748	109.1			
				3	4.559	10.2			
				4	6.747	108.7			
ADJUSTMENT (level remains set up at 2 and sighted at R ₄)									
Adjust cross hair to: $R_4 \pm \left[\frac{(cd_4)}{100} \right] = \pm \left[\frac{(\quad)}{100} \right]$ Repeat collimation test after adjustment									
CLOSURE ERROR COMPUTATIONS									
Circuit No.	No. of Inst. Setups (N)	Allowable closure error 0.003 * (N) ^{1.5}	Closure Error (CE)	CE/N (take to 0.0001)	NOTES or SKETCHES:				
1	8	0.008	-0.004	-0.0005					

Figure 16. Complete set of level notes for a level circuit with eight instrument setups.

U.S. DEPARTMENT OF THE INTERIOR U.S. Geological Survey Gaging Station Level Notes									
Station Number: 09261000		Station Name Green River near Jensen, Utah		Party MLF	(inst.) TAK				
Date April 19, 2009									
SUMMARY OF OBJECTIVE POINTS						INSTRUMENT			
Object	Adj. 1 st Elev.	Adj. 2 nd Elev.	Diff. (1 st Elev. - 2 nd Elev.)	Final Elev. (Ave. of Adj. Elev.)	Make/Model: TopCon DL-102C				
RM1	Given			15.410	Serial Number: 1202				
RM3	25.685	25.688	-0.003	25.686	Collimation (optical): 0.0025				
RM4	16.290	16.290	0.000	16.290	Collimation test date: April 19, 2009				
ChkBar	26.471	26.472	-0.001	26.472	Collimation (digital): 0.0020				
					Collimation test date: April 19, 2009				
					ROD				
Scale material: Fiberglass CTE 20*10^-6 (1F^-3 or 1/C^3)									
CTE conversions: (1/°F * 1.8 = 1/°C) and ((1/°C)/1.8 = 1/°F)									
Temperature (T): Rod: 70.6F or °C; Air: 70.6F or °C									
Standard temp (T ₀): 68°F or 20°C or other: _____									
Given/Origin elevation: 15.410									
Max elevation of objective point: 26.472									
Min elevation of objective point: 3.114									
Max elevation difference (L): 12.296									
C ₁ = CTE * L(T-T ₀) C ₁ = <0.0005									
Other devices used as rod (list): none									
GAGE READINGS						GAGE RESET			
Time	WS	DCP	Ref. WW	Ref. WW	Rod taped (circle): yes no	Rod level used (circle): yes no			
12:05		3.11		3.11			Ref. WW	DCP	
12:30	3.114	3.11		3.11					
12:35	3.114	3.11		3.11			Found	3.11	3.11
12:55		3.11		3.11			Left	3.11	3.11
WEATHER: Clear, sunny, warm									
NOTES: No changes needed or made.									
Computed by: MLF Checked by: TAK Date: April 22, 2009									

Table 7. Standards and select requirements for leveling.[Modified from Federal Geodetic Control Committee (1984) and McCormac (1983). *D* is distance in kilometers. ft, foot]

Order	First		Second		Third
Class	I	II	I	II	
Recommended uses	Basic framework of the National Network and metropolitan area control. Regional crustal movement studies. Extensive engineering projects. Support for subsidiary surveys.		Secondary frame-work of the National Network and metropolitan area control. Local crustal movement studies. Large engineering projects. Tidal boundary reference. Support for lower order surveys.		Small-scale topographic mapping. Establishing gradients in mountainous areas. Small engineering projects. May or may not be adjusted to the National Network.
Maximum collimation error (ft/100 ft)	0.005	0.005	0.005	0.005	0.01
Maximum time interval (days) between collimation error determinations	1	1	1	1	7
Rod level verticality maintained to within (ft)	10	10	10	10	10
Maximum sight length (ft)	164	197	197	230	295
Minimum ground clearance of line of sight (ft)	1.6	1.6	1.6	1.6	1.6
Maximum circuit misclosure (circuit-closure error limit) (ft)	$ 0.010\sqrt{D} $	$ 0.013\sqrt{D} $	$ 0.020\sqrt{D} $	$ 0.026\sqrt{D} $	$ 0.039\sqrt{D} $

Table 8. Standards and adopted requirements for gaging station levels.[*n* is the total number of instrument setups in a circuit. ft, foot]

Adopted standards and requirements	
Order	Third
Use	Gaging station levels
Maximum collimation error (ft/100 ft)	$ 0.003 $
Maximum time interval (days) between collimation error determinations	7
Rod level verticality maintained to within (ft)	10
Maximum sight length (ft)	164
Minimum ground clearance of line of sight (ft)	1.6
Maximum circuit misclosure (circuit-closure error limit) (ft)	$ 0.003\sqrt{n} $

Assessing a Level Circuit and Adjusting Elevations

An acceptable set of gaging-station levels has two FSs, each from a different instrument height, to a minimum of two independent reference marks, all reference points, all gages, and the water surface. A third independent reference mark is the origin, or starting point, with a given elevation from which the initial instrument height is determined. The origin reference mark is considered to be the most stable and should be explicitly identified as such in the current station description for the gaging station. The first criterion for a valid level circuit is that the absolute value of the closure error for the leveling circuit must be less than or equal to the closure error limit computed using equation 5 and must not exceed $|0.015|$ ft regardless of the number of instrument setups. If the closure error exceeds the closure error limit, the entire level circuit must be re-run.

Following the completion of a level circuit for which the closure error falls within the specified limit, elevations of objective points are adjusted by distributing the determined closure error of the circuit to each instrument setup. Closure error is associated with instrument setups made throughout a leveling circuit and instrument (collimation) error if present and sightline distances are not balanced. Closure error is introduced into a circuit during the determination of instrument heights because of errors in FS readings taken on the turning points, or errors in BS readings taken on the turning points or origin. Closure error is not affected by side shots, shots taken on objective points from a given instrument setup. In the levels methods and techniques presented in this manual, the specific instrument setup(s) where error is incurred cannot be determined; therefore, closure error is distributed in a manner that assumes the error accumulates with each instrument setup. The methods described by Thomas and Jackson (1981) should be used to adjust the elevations of objective points by distributing the circuit closure error uniformly to the different instrument setups of the level circuit. To determine adjusted elevations for any objective point in a circuit, use the equation

$$E_{adj} = [(HI_{seq})(CE / n)] + E_{unadj}$$

(6)

where

- E_{adj}

is the adjusted elevation of an objective point,
- HI_{seq}

is the sequential instrument setup number associated with the foresight taken to that objective point (the first instrument setup is 1, second instrument setup is 2),
- CE

is the closure error for the circuit computed as the given origin elevation minus the final elevation of the origin from the final instrument setup,
- n

is the total number of instrument setups in the circuit, and
- E_{unadj}

is the unadjusted elevation of the objective point.

[Table 9](#) gives an example of a four-instrument setup level circuit where a closure error of -0.005 ft is distributed to the four instrument setups and the applied error is accumulated with the sequence of instrument setups. The absolute value of the closure error of the circuit, 0.005 ft, is less than the closure error limit, |0.006| ft, computed using equation 5. The closure error of -0.005 ft shows that the final elevation of the origin reference mark was 0.005 ft higher than the given elevation. The adjustment, calculated by dividing the closure error by the number of instrument setups and multiplying by the sequential instrument setup number should be rounded to a precision of

0.0001 ft. This adjustment should be added to the unadjusted elevations to obtain adjusted elevations that should then be rounded to a precision of 0.001 ft. Rounding should follow the technique shown in [table 10](#) (U.S. Geological Survey, 1991).

The closure-error criterion of a valid level circuit discussed above ensures that systematic errors associated with instrument setups are not introduced into a leveling circuit. The second criterion of a valid level circuit is that the absolute value of the difference between the adjusted first and second elevations for each objective point must be less than or equal to 0.005 ft. This criterion, based on the examination of side shots, ensures that systematic errors specific to each objective point are not present in their final elevations. If the absolute value of the difference between the adjusted first and second elevations for an objective point is greater than 0.005 ft, two new FSs, each from independent instrument heights, must be taken. A new closure error for this abbreviated circuit is determined, and the closure error must fall within the previously specified tolerance. The new elevations of the objective points are adjusted, as described above, and the absolute value of the difference between the adjusted first and second elevations must be less than or equal to 0.005 ft. Elevations for some objects are determined by sighting them in at the cross hair of the level, such as the bottom of a wire weight or an electric tape gage weight. When running levels to these types of objects, they are either lowered or raised until they are at the cross hair of the level. Therefore, determined elevations, which are equal to the instrument height, vary from one instrument setup to another. For this reason, these types of objects are not subject to the elevation difference criterion. Although it may be possible to compare the difference between the height of the instrument and the dial reading for the 2 FSs, the 0.01 ft precision of the gages prohibits a comparison that can be held to the |0.005| ft tolerance. Because taking precise FSs on the water surface is often difficult, water-surface elevations are not subject to the |0.005| ft elevation difference criterion as long as uncertainties in the water-surface measurements are noted (for example,

Table 9. Computed adjustment values for each instrument setup of a four-instrument level circuit with a closure error of -0.005 foot.

[Closure error of circuit: -0.005 foot. The final elevation of the origin reference mark was 0.005 foot higher than the given elevation]

Sequential instrument setup	Amount to add to initial elevations (foot)
1	-0.0012
2	-0.0025
3	-0.0038
4	-0.0050

Table 10. Technique for rounding off numbers.

[Modified from Hansen (1991)]

Example	Original number	Rounded number	
1	0.32891	0.329	If the first of the discarded digits is greater than 5, add 1 to the digit representing the third significant figure
2	47,543	47,500	If the first of the discarded digits is less than 5, leave the digit representing the third significant figure unchanged
3	11.65	11.6	If the first of the discarded digits is 5, all the following digits are zero, and the digit representing the third significant figure is even, leave the digit unchanged.
4	22.75	22.8	If the first of the discarded digits is 5, all the following digits are zero, and the digit representing the third significant figure is odd, round the digit up to the next even number.
5	18.05	18.0	If the first of the discarded digits is 5, all the following digits are zero, and the digit representing the third significant figure is zero, leave the digit unchanged.
6	18.051	18.1	If the 5 is followed by any of the digits 1 through 9, add 1 to the digit representing the third significant figure

± 0.01). Final elevations for objective points are calculated by averaging the adjusted first and second elevations. The elevation for the origin reference mark is still the given value. To properly determine whether a gage needs to be reset, and if it is reset, to ensure that it is reset correctly, levels must be computed and checked in the field. The level note form provided in [appendix C](#) adheres to the gaging-station levels procedures and requirements presented here.

Methods for Taking Foresights on Gages and the Water Surface

Two FSs must be taken to all gages and the water surface from two different instrument heights when levels are run at a gaging station. Levels are run at gaging stations to make sure that all gages are properly set and accurately reporting water-surface elevation in the gage datum. Therefore, these FSs are the most important shots taken. When gages do not agree with the gage datum, the survey crew must accurately reset the affected gages. Many different types of gages are used at gaging stations, and various techniques are used to take a FS on each gage type and the water surface. Some of the more common techniques for taking a FS on gages and the water surface are presented below.

Vertical Staff Gage

Vertical staff gages are perhaps the type of gage most commonly found at gaging stations. Staff gages are placed in direct contact with the water. They can be placed inside stilling wells or attached to various objects on the banks of a stream. Stations on streams that have a large range in stage often have a series of staff plates that are installed in vertical intervals along a sloping bank. While it is feasible to directly

read staff plates using an engineer's level, this technique is usually not practical. The most common method for taking a FS on a staff plate is to establish a reference point by partially driving a nail or screw into the staff plate backing next to the plate. The elevation of the reference point, in relation to the staff plate, should be read from the plate and noted. To take the FS, a rod should be held level on the reference point ([fig. 17](#)). For the staff plate to agree with the gage datum, the elevation of the reference point, read using the plate, should equal the elevation computed from the FS. Staff gages consisting of multiple plate sections should have a FS taken on all sections or a measuring tape can be used to measure from a location where the FSs have been taken on one plate section, such as a reference point, to each of the other plate sections. For obvious reasons, staff plates must be installed vertically. A carpenter's level should be used to verify that plates are vertical when levels are run.

Electric Tape Gage

Electric tape gages (ETG) are used in stilling wells to safely measure the water surface inside the well without entering the confined space. Electric tape gages are permanently mounted on a shelf inside the stilling well. These gages consist of a spooled graduated steel tape with an attached weight and an analog voltage readout ([fig. 18](#)). The gage is connected to a battery terminal, and a lead wire from another battery terminal is extended below the water surface in the well. To obtain a gage reading, the ETG weight is spooled down to the water, and when the bottom of the weight contacts the water surface, the circuit is closed and the voltage dial responds. The graduated tape is read at a reading index, called the ETG index, marked by a line and located just above the surface on which it is mounted.



Figure 17. Foresights being taken on staff plates by holding leveling rods on nails driven into backing boards.





Figure 18. Electric tape gage with a pocket rod held on a stack of coins at the elevation of the index.

When running levels at a station with an ETG, FSs should be taken on the ETG index, and when feasible, FSs should also be taken on the bottom of the weight. A slight gap exists between the ETG index and the object on which it is mounted. When taking a FS on the ETG index, be sure that the rod, which is likely a carpenter's ruler, a measuring tape, or a "pocket rod," is set at the level of the ETG index. A stack of coins on the shelf can usually be used as a stable place to hold the rod and obtain an accurate FS ([fig. 18](#)).

Foresights taken on the bottom of the ETG weight should be taken with the weight as close to the water surface as possible. However, unless the stilling well is equipped with a clean-out door, the FS on the bottom of the weight will likely be taken with the weight located just below the instrument shelf. The level should be set up so that the instrument height is at least one length of the weight lower than the ETG index. To take a FS, the ETG weight should be lowered until the bottom of the weight is at the cross hairs of the level. While the weight is at this location, the gage height should be read at the ETG index. If the ETG agrees with the gage datum, the instrument height will equal the reading at the ETG index. Electric tape gages are susceptible to any movement of the shelter they are installed in. They are also sensitive to any movement of the shelf that they are mounted on. Adding weight, such as a larger battery, to an instrument shelf may cause the shelf to flex downwards, which could change the elevation of the ETG index and cause incorrect gage height readings.

Wire-Weight Gage

Wire-weight gages are most often installed on bridge structures ([fig. 19](#)), but can also be installed on a cantilever on a stream bank ([fig. 20](#)). Suspended above the water surface, wire-weight gages are weighted cables that are spooled on a calibrated drum. To take a gage reading, the weighted cable is lowered until the bottom of the weight contacts the water surface. The gage-height value is read from the digital counter and the calibrated drum of the wire-weight gage. The contact with the water surface is determined visually, which introduces uncertainty associated with the sightline distance, lighting, and the surface characteristics of the water. When running levels to a wire-weight gage, a FS should be taken on both the check bar ([fig. 19](#)) and the bottom of the weight near the water surface. For cantilever installations (only), FSs on the check bar are not required as they are not associated with the elevation of the weight of the wire-weight gage; however, tracking elevations of the check bar of a cantilevered wire-weight gage may be useful in determining stability of the cantilever structure.

Foresights taken on the check bar of a traditional wire-weight gage are taken with the check bar in its outer position (away from the object it is mounted on) using a leveling rod. Foresights taken on the bottom of the weight for all wire-weight gages should be taken from an instrument set up on the low water bank, such that the FS is taken with the wire weight as close to the water surface as possible. The wire weight should be lowered until the bottom of the weight is at the cross hairs of the level. With the weight at this location, the gage height should be read from the digital counter and the calibrated drum. If the wire-weight gage agrees with the gage datum, the instrument height will equal the reading of the wire-weight gage.

A wire-weight gage has several potential sources of error to be considered when checking it (Kennedy, 1990). The drum is calibrated so that every rotation accounts for a distance traveled by the weight. For this reason, the cable should be evenly spooled on the drum. Wire weights tend to spin as they are lowered and raised. If the cable is not allowed time to unwind, it will be twisted and thus shorter. This can lead to incorrect gage heights. After the cable reaches its proper length, the wire weight should be spooled back up onto the drum. The weight should be placed on the check bar, and the associated check bar reading should be noted. The weight can then be lowered to the water surface to determine the gage height. These procedures should be followed when taking a FS on the bottom of the weight as well.

Variations in the drum and the cable diameter of a wire-weight gage can cause calibration errors (Kennedy, 1990). Gage height readings from a wire-weight gage represent a count of the number of revolutions made by the calibrated drum before the weight contacts the water surface. Any differences between the actual diameters of the drum and the cable, and the diameters programmed into the revolution counter will accumulate as the drum revolves. Fortunately, because of this accumulation, these calibration errors are linear and can be corrected for once recognized and documented.

At most gaging stations, wire-weight gages should be set to accurately read low water elevations. If a wire-weight gage is properly set to read low water elevations, a calibration error can be recognized if the check bar reading differs from the check bar elevation determined from levels. By preparing a graph of the wire-weight gage readings for the bottom of the weight and the check bar and the elevations from levels, corrections for gage height readings at different stages can be determined ([fig. 21](#)). The equation for this linear relation is shown in [figure 21](#) and can be used to compute the correction to the gage reading by inputting the wire-weight reading. When such corrections are defined, a plot and an equation similar to these should be prepared and stored at the gaging station. The sources of error for wire-weight gages discussed here are usually negligible for wire-weight gages mounted less than 15 ft above the water, and increase with greater distances (Kennedy, 1990).

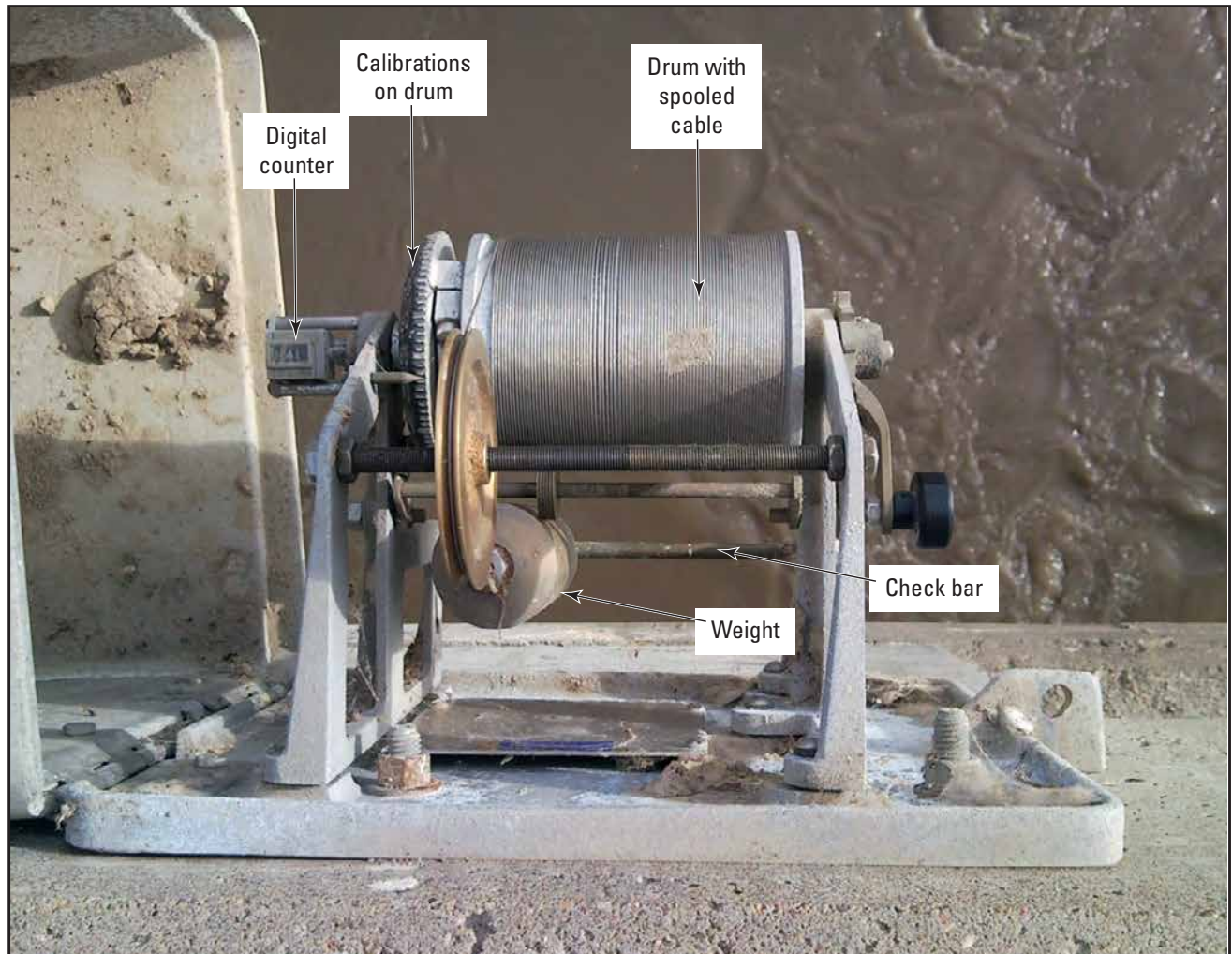


Figure 19. Wire-weight gages mounted on bridges.



Figure 20. Cantilevered wire-weight gage located to the left of a stilling well.

Crest-Stage Gage

Crest-stage gages (CSG) record the peak water-surface elevation, or gage height, as a high water mark consisting most often of a cork line on a stick inside a pipe. A vertically installed pipe, which is capped on the top and bottom, communicates with stream water by a set of holes drilled into a cap on the bottom of the pipe. As the water-surface elevation decreases, the maximum level of the water is recorded by a cork line on a stick contained within the pipe. To recover the recorded maximum instantaneous gage height, the stick is removed from the pipe and the distance from the bottom or the

top of the stick to the cork line is measured. If the index of the CSG is located at the bottom, the stick is measured up from the bottom. If the index is at the top, the stick is measured from the top.

Foresights taken on the index of a CSG can usually be taken with a leveling rod. The location where the leveling rod is held depends on location of the index. Often, the bottom cap has a metal stud attached in the center where the stick rests ([fig. 22](#) inset). The elevation of this stud is equal to the cap surface where the threads begin, and the FS is taken by holding the rod on the top of the bottom cap ([fig. 22](#)). A bolt installed through the pipe near the bottom provides a surface

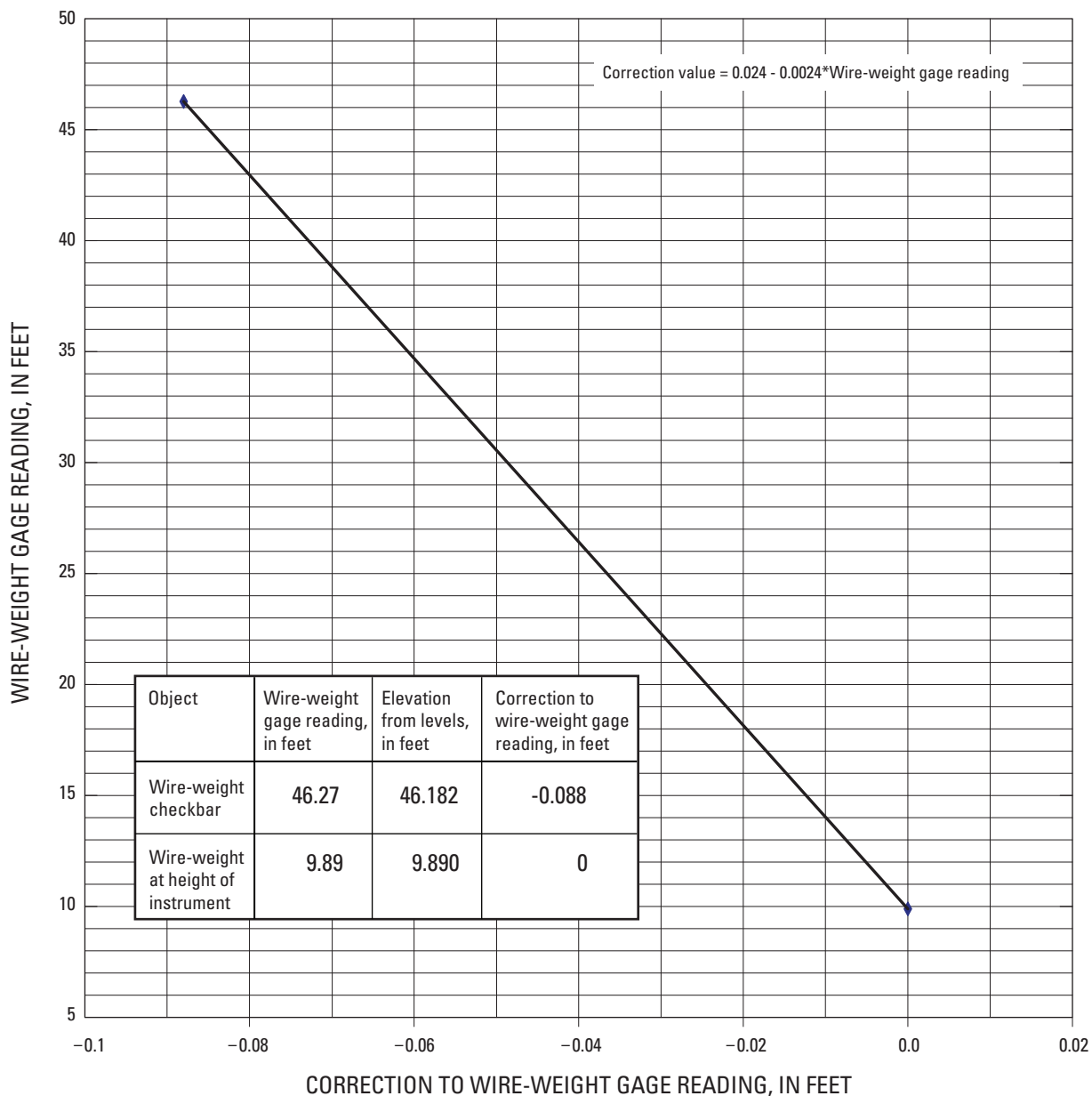


Figure 21. Stage-related wire-weight corrections determined from levels.

for the stick to rest on and is an excellent index to hold a rod on to take a FS ([fig. 23](#)). For both of these CSG configurations, the maximum stage is determined by measuring from the bottom of the stick to the cork line high water mark and then adding that value to the elevation of the CSG index. Some CSGs have the index on the top of the stick. Foresights are taken by holding the leveling rod on top of the stick at the index, and the maximum stage is determined by measuring from the top of the stick down to the cork line high water mark and then subtracting that value from the elevation of the CSG index.

Inclined Staff Gage

Inclined staff gages are permanent structures that are installed at about the same slope as the streambank ([fig. 24](#)). The scale along the incline is set to represent the water-surface elevation. The slope of these gages minimizes damage caused by debris and ice. The permanence of the inclined staff gages makes them very difficult to adjust if they disagree with the gage datum. Foresights are taken on several foot marks throughout the gage's range, from one or more instrument heights (Kennedy, 1990). If the inclined staff gage is a composite of multiple slopes, at least 2 FSs must be taken on each slope.



Figure 22. Crest-stage gage where the index is the bottom cap. Inset photograph of the bottom cap showing the internal stud.

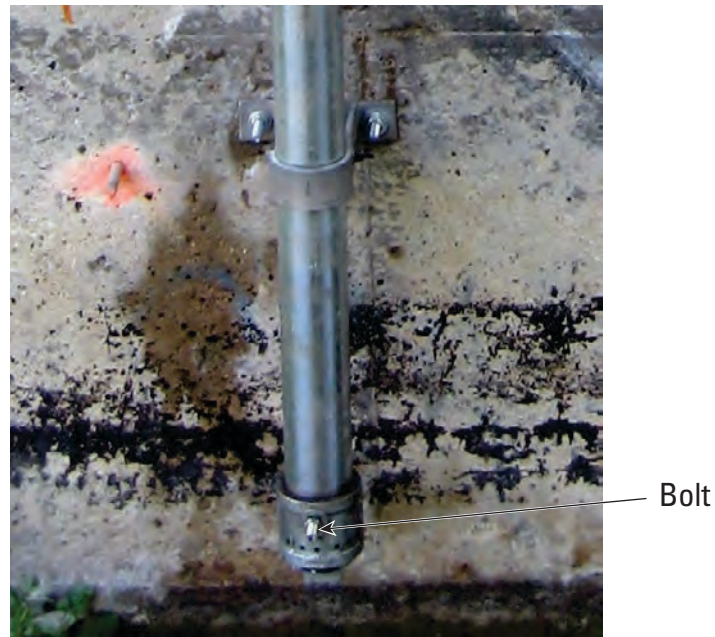


Figure 23. Crest-stage gage where the index is a bolt installed through the pipe.

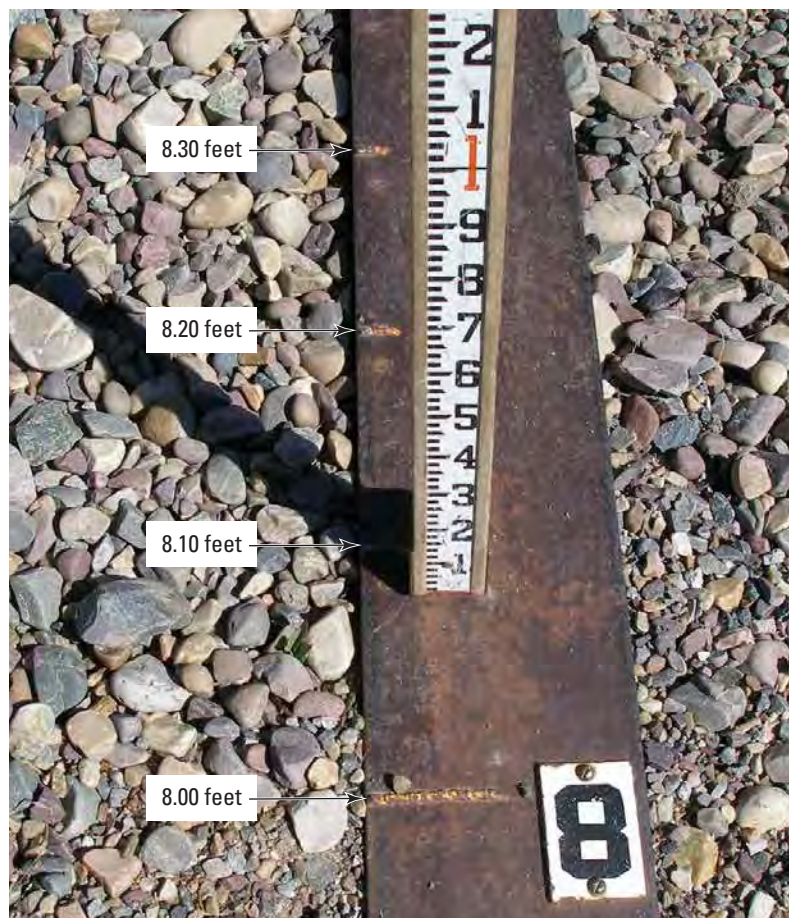


Figure 24. Inclined staff gage installed on a streambank.

Water Surface

Traditional gaging stations are established to measure the elevation of the water surface. When running levels at gaging stations, two FSs are required to be taken on the water surface. These FSs can be difficult to obtain because the water surface is not a firm object and therefore a rod cannot be held directly on it. Also, the water surface may not be vertically stable at the time and (or) location of the measurement. There are three techniques that can assist in taking precise and accurate FSs on the water surface. For streams that are shallow along the banks, a stable object such as a rock, a stake, or a screwdriver driven to the water surface, or even the wading boot of the rod man can be used as a stable location to hold a leveling rod. These objects will have to be positioned in a manner that allows a visual determination of the water surface and firm placement of the bottom of the leveling rod. A second technique that can be used if stream conditions (including depth and velocity) allow is to hold the rod on the streambed, take a FS of the elevation of the streambed, and manually read the depth of the water off of the rod. To determine the elevation of the water surface, compute the elevation of the streambed and add the water depth to it. Finally, if the conditions of the stream do not allow both of these techniques, a reference point (either a temporary or a permanent one) can be established as close as possible to the water surface. From this reference point, a measuring tape can be used to tape down to the water surface. An estimate of the uncertainty in the FS taken on the water surface should always be provided by the rod man and included in the remarks on the level notes.

Resetting Gages Based on the Results of Levels

The main purpose of running levels at gaging stations is to verify that gages, specifically the primary reference gage, are properly set to read the stage in the gage datum. The primary reference gage should be reset if the absolute value of the difference between the elevation reading of the reference gage and the gage datum is greater than or equal to 0.015 ft. Before the gage is reset, the level circuit containing the gage must be completed. A complete level circuit is one in which circuit closure error is less than or equal to the established limit, adjustments associated with closure error have been applied, differences between the adjusted first and second elevations of objective points have been computed, and it has been verified that these differences meet the established criteria. Final elevations for all gages are determined and the computations for the circuit are checked. If the reference gage needs to be reset, it should be reset on the basis of the final computed elevation.

The survey crew must verify and document that the gage was reset correctly. There are three verification methods: (1) an abbreviated level circuit consisting of a closed objective point (part of a completed and valid level circuit), the gage, and a turning point (2) a tape down from a reference point that was part of a completed and valid circuit; and (3) an independent check of the water-surface elevation and gage reading. Resetting auxiliary gages (those other than the primary reference gage) also is recommended when the difference between the elevation reading of the auxiliary gage and the gage datum is greater than or equal to $|0.015|$ ft.

Methods for Simplifying Complex Level Circuits

Complex level circuits for the purposes of this discussion are level circuits that require more than two instrument setups to obtain two independent FSs for all objective points. In a complex circuit, elevation must be carried from one instrument setup location to another by using intermediate turning points to establish more than two instrument heights. After obtaining all first FSs and before obtaining second FSs, an independent turning point that is not an objective point is required to establish the first instrument height from which second FSs will be taken. In contrast, simple level circuits have only two instrument setups, with the second instrument height being established from an independent turning point that is not an objective point to take second FSs.

The error tolerances set forth for circuit closure and for differences between adjusted first and second elevations are strict. The method described by Thomas and Jackson (1981) for distributing closure error by instrument setup assumes that error is evenly accumulated through the level circuit. While this assumption may not always be true, this method provides the best means available for distributing closure error because it is difficult, if not impossible, to determine the specific instrument setups where errors are incurred within a leveling circuit. Unfortunately, this method of error distribution, and its underlying assumption, can lead to incorrect adjustments to valid elevations.

Level circuits with more than two instrument setups have more opportunity to incur error in both closure and final elevations. By limiting the number of instrument setups in a circuit, the potential for error can be minimized. In most cases, by implementing some of the techniques discussed below, a level circuit consisting of more than two instrument setups can be broken down into a series of independent level circuits, each having a minimum of two instrument setups.

Separating Complex Level Circuits into a Set of Sequentially Closed Simple Level Circuits

Most complex level circuits can be broken down into a series of simple level circuits that are closed in sequence. A simple level circuit requires a turning point that is not an objective point, and a complex level circuit needs to carry elevation using an objective point(s) or an intermediate turning point(s), and requires at least one turning point that is not an objective point.

Level notes and a leveling diagram for a complex level circuit are shown in [figure 25](#). Shots from a single instrument setup cannot be taken on all of the objective points of this circuit: RM1, RM2, RM3, the ETG index, the bottom of the ETG weight, the outside staff gage, and the water surface. RM1 (the origin) and RM2 are located up a slope above the other objective points at the site. This level circuit uses an intermediate turning point (TP1) to carry elevation down to the remaining part of the circuit. From the second instrument setup, FSs are taken on the ETG index, the outside staff gage, the water surface and RM3. RM3 is then used as an intermediate turning point to establish the third instrument height, which is needed to take a FS on the bottom of the ETG weight. An independent turning point is established (TP2) and the circuit is shot in reverse order back to RM1.

The complex level circuit described above can be broken down into three simple level circuits that are sequentially closed. Level notes and a leveling diagram for the three simple level circuits are shown in [figure 26](#). The first simple circuit consists of objective points RM1, RM2, and TRM1. RM1 is the origin and is used as the starting point to set the initial instrument height. A temporary reference mark, TRM1, is established in the first simple level circuit to carry elevation to the second circuit. Note that the location of TRM1 is the same as that of the first turning point in the complex leveling circuit diagram discussed above. An independent turning point (TP1) is established to ensure that two FSs are taken on each of the objective points for the first level circuit, which includes RM2 and TRM1. This first circuit is closed with the second FS taken on RM1. The second simple circuit consists of objective points TRM1, RM3, the ETG index, the outside staff gage, and the water surface. The initial height of the instrument for the second circuit is determined from TRM1 which had two FSs taken on it in the first circuit. The second instrument height is determined from an independent turning point (TP2). This circuit is closed with the second FS taken on TRM1. Finally, the shots to the bottom of the ETG weight are made from a final simple circuit in which the initial instrument height is determined from RM3, which had two FSs taken on it in the second circuit. The second instrument height for the third simple circuit is determined from an independent turning point (TP3), and the circuit is closed with the second FS taken on RM3.

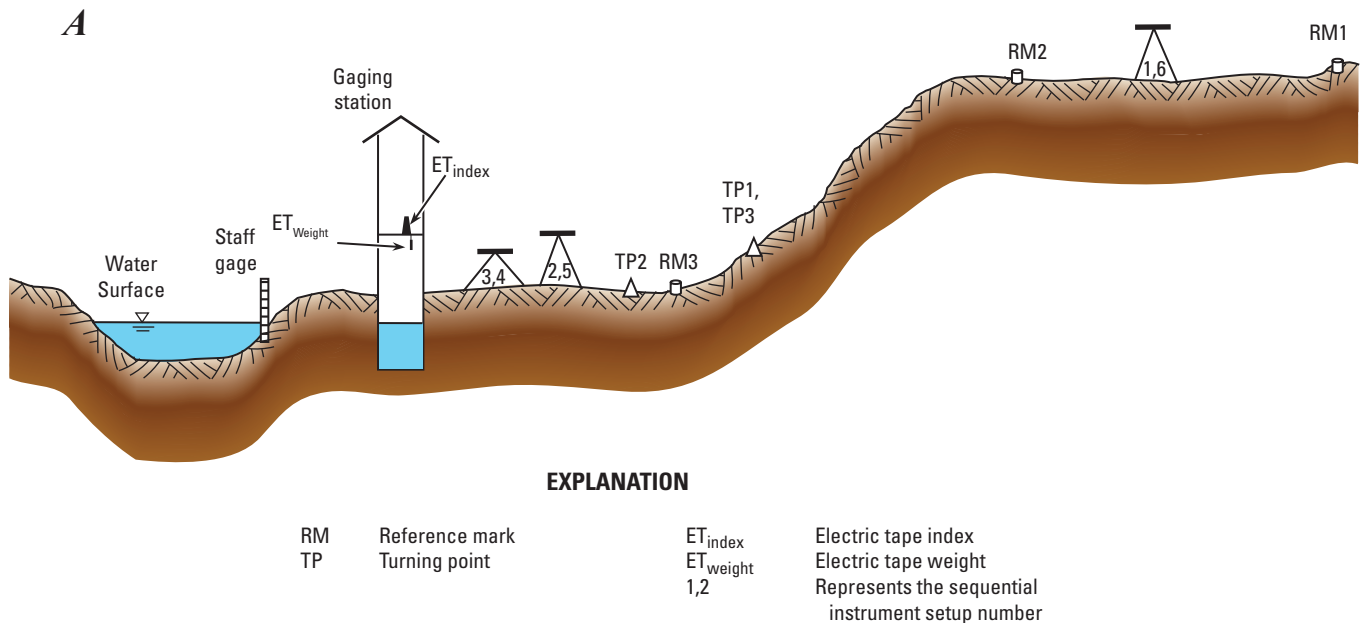


Figure 25. A. Leveling diagram showing objective points in a complex circuit and B. level notes for a complex leveling circuit.

Both the complex level circuit and the set of three simple circuits have a total of six instrument setups. A distinct difference is that in the complex circuit, elevation is carried through the six instrument setups consecutively, whereas in the simple circuits, elevation is carried through two setups at a time. The six setups in the complex circuit represent six opportunities where errors can occur. We assume that if present, these errors accumulate and will be represented in the closure error for the circuit. Where these types of errors occur within the circuit cannot be determined, and in a case such as this one, the closure error is distributed evenly to each of the six instrument setups. In the set of three simple level circuits, only two instrument setups were needed in each circuit to take FSs on the objective points and close the circuit. That created only two locations in each circuit where error could be introduced. All three simple circuits were closed sequentially, which ensured that elevations assigned to TRM1 and RM3, used to determine instrument heights for the second and third circuits, respectively, were valid before running those circuits. If an error is introduced into one of the simple circuits, that error can be recognized and rectified before shooting all objective points twice at the site. The above examples also demonstrate that sequentially closing the simple circuits eliminates the need to go back up the slope to the origin reference mark, RM1. The accuracy and efficiency in running levels at gaging stations can be improved by breaking down a complex level circuit into a series of simple level circuits. Strategic placement of permanent reference marks, such as in

locations where elevation has to be carried up or down a slope, would reduce the need to establish temporary reference marks or intermediate turning points for every level run.

Using a Suspended Weighted Steel Tape to Carry Elevation to or from a Bridge Structure

Many gaging stations are separated by a range in elevation that is greater than the length of one extended leveling rod. This often happens when reference marks, reference points, and (or) the wire-weight gage are located on a bridge that is relatively high above the stream, and other reference marks, reference points, various gages, and the water surface are located well below the bridge deck. Kennedy (1990) describes how a weighted steel tape can be suspended from a bridge and be used as a long leveling rod to carry elevation from a lower streamside level circuit to a higher level circuit on the bridge deck (and vice versa). This method incorporates running a series of simple level circuits. The effects of thermal expansion and contraction, tension, and wind must be understood and the precision and accuracy requirements attainable before using a suspended steel tape for levels (see section on “[Leveling Rods](#)”). Two sets of level notes, one presenting the bridge-down method and the other the ground-up method, and a leveling diagram are provided as an example of how to use a suspended weighted steel tape to run a series of simple level circuits at a gaging station ([fig. 27](#)).

A

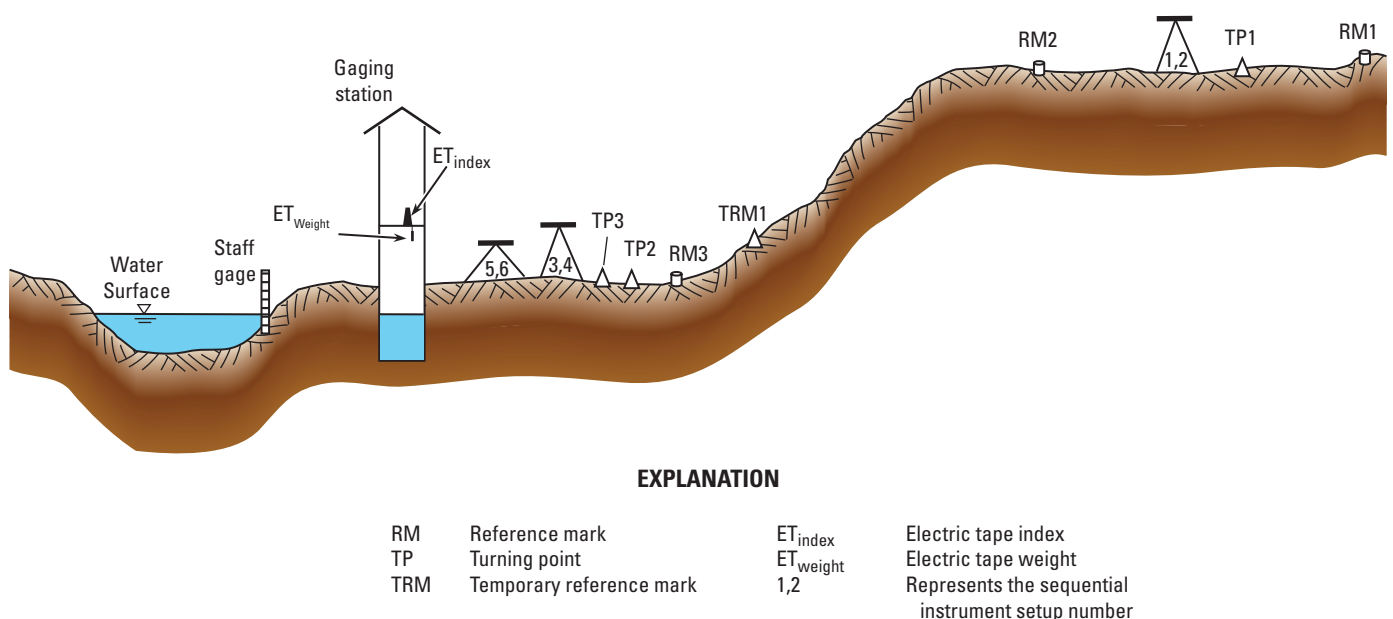


Figure 26. A. Leveling diagram and B. level notes showing 3 simple level circuits used to replace 1 complex level circuit.

CLOSURE- ERROR ADJUSTMENT TO HI	ADJUSTED 1 st ELEVATION	ADJUSTED 2 nd ELEVATION	DIFFERENCE (AE1 -AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
0.0000					26.011	<i>Given, Origin</i>
	25.235		0.000	25.235	25.235	
	16.514		0.000	16.514		
0.0000						
		16.514				
		25.235				
0.0000						<i>Given</i>
	12.300		0.000	12.890	12.890	
	15.210		0.000	15.210	15.210	
	10.340		0.000	10.340	10.340	
	9.550					<i>+/- 0.01, DCP = 9.55</i>
0.0000						
		9.550				<i>+/- 0.01, DCP = 9.55</i>
		10.340				
		15.210				
		12.300				
0.0000						<i>Given</i>
	14.100					<i>ETG ready 14.10</i>
0.0000						
		14.155				<i>ETG ready 14.16</i>

OBJECT	BS	CORRECTED BS BS+(CTE* BS*(T-T ₀))	HEIGHT OF INSTRU- MENT (HI)	FS	CORRECTED FS FS+(CTE* FS*(T-T ₀))	ELEVATION	Remarks
RM1	4.655		30.666			26.011	<i>Braß cap uplope 50' E</i>
RM2				5.431		25.235	<i>Braß cap uplope 35' E</i>
TRM1				14.152		16.514	
TP1				5.664		25.002	
TP1			<i>Moved Instrument</i>				
TP1	5.748		30.750				
TRM1				14.236		16.514	
RM2				5.515		25.235	
RM1				4.739		26.011	
CE = 26.011 - 26.011 = 0.000 CElimit = 0.003 * (√(2*setup ₂)) = 0.004							
TRM1	1.586		18.100			16.514	
RM3				5.800		12.300	<i>Braß cap 12' E</i>
ETGindex				2.890		15.210	<i>Mounted on shelf</i>
OG				7.760		10.340	<i>Staff, Nail @ 10.34</i>
WS	@13:25			8.550		9.550	<i>ETG(ref) = 9.55, OG=9.55</i>
TP2				1.576		16.524	
			<i>Moved Instrument</i>				
TP2	1.639		18.163				
WS	@13:30			8.613		9.550	<i>ETG(ref) = 9.55, OG=9.55</i>
OG				7.823		10.340	<i>Nail @ 10.34</i>
ETGindex				2.953		15.210	
RM3				5.863		12.300	
TRM1				1.649		16.514	
CE = 16.514 - 16.514 = 0.000 CElimit = 0.003 * (√(2*setup ₂)) = 0.004							
RM3	1.800		14.100			12.300	
ETGheight				0		14.100	<i>Ref gage, direct read</i>
TP3				2.655		11.455	
			<i>Moved Instrument</i>				
TP3	2.710		14.155				
ETGheight				0		14.155	<i>Ref gage, direct read</i>
RM3				1.855		12.300	
CE = 12.300 - 12.300 = 0.000 CElimit = 0.003 * (√(2*setup ₂)) = 0.004							

B

Figure 26. Continued.

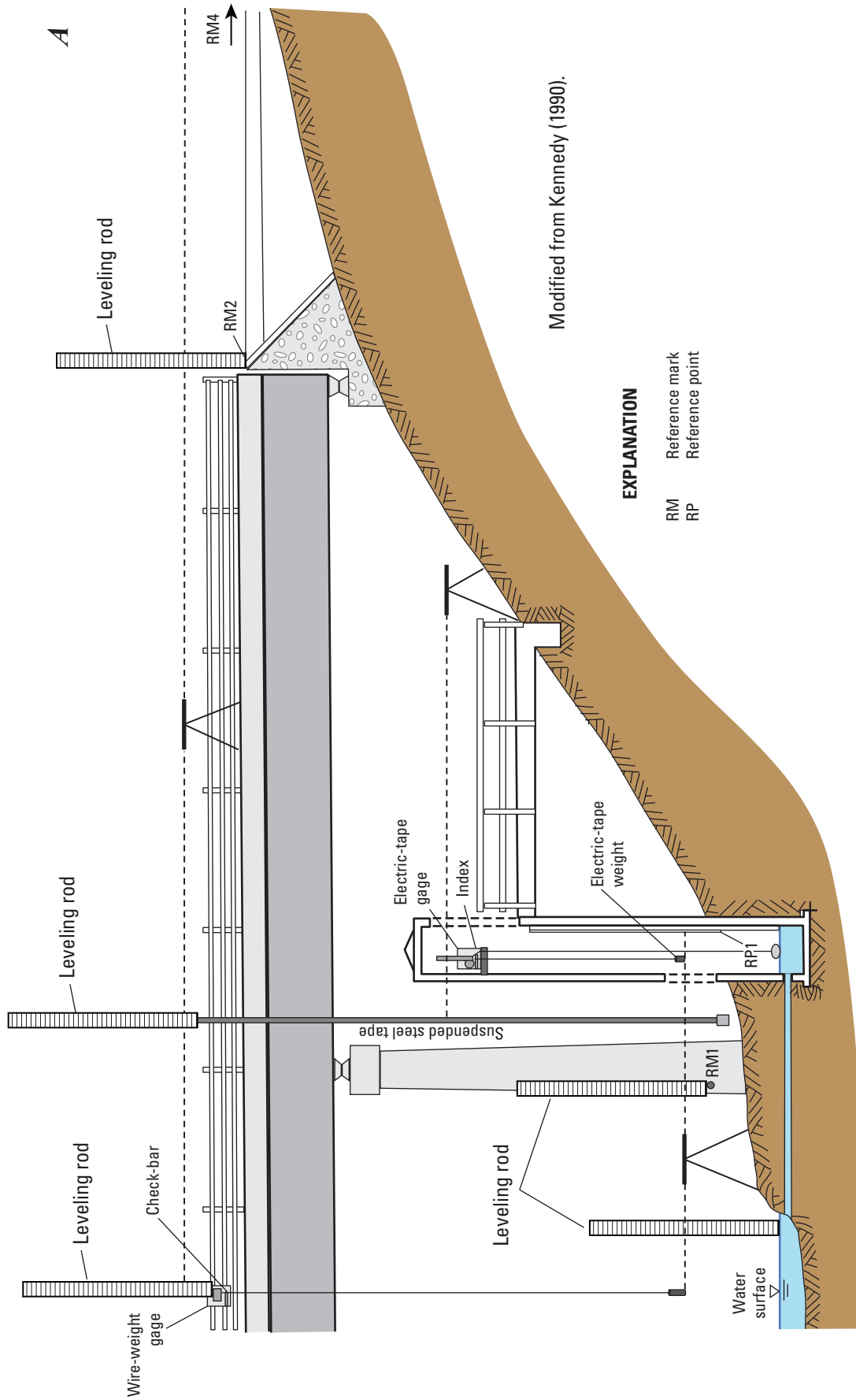


Figure 27. A. Leveling diagram and B, C. level notes illustrating the use of a suspended steel tape to carry elevations from a bridge down to a streamside gage location and from a streamside gage location up to a bridge.

CLOSURE- ERROR ADJUSTMENT TO HI	ADJUSTED 1 st ELEVATION	ADJUSTED 2 nd ELEVATION	DIFFERENCE (AE1 -AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
0.0000					42.806	Given Origin
	41.914		0.000	41.914	41.914	
	44.741		0.000	44.741	44.741	Check bar reads 44.74
	3.373					Bottom of tape
0.0000						
		3.373				
		44.741				Check bar reads 44.74
		41.914				
		24.909				
0.0000	24.909		0.000	24.909	24.909	Given
		24.909				
	3.373		0.000	3.373		Given
0.0000						
	9.434					ETG reads 9.43
	6.203		0.000	6.203	6.203	
	1.426					+/-0.01, DCP=1.43
	9.434					WM reads 9.43
0.0000						
		9.568				WM reads 9.57
		1.426				+/-0.01, DCP=1.43
		6.203				
		9.568				ETG reads 9.57
		7.106				

OBJECT	BS	CORRECTED BS BS+(CTE* BS*(T-T ₀))	HEIGHT OF INSTRU- MENT (HI)	FS	CORRECTED FS FS+(CTE* FS*(T-T ₀))	ELEVATION	Remarks
RM2	3.410		46.216			42.806	Brow cap right abutment
RM4				4.302		41.914	Brow cap on sidewalk 75N
WMCB				1.475		44.741	
Tape				42.843		3.373	Clamped @ 40', rod=2.843
TP1	2.682		46.003	2.895		43.321	Moved Inst
Tape				42.630		3.373	Clamped @ 40', rod=2.630
WMCB				1.262		44.741	
RM4				4.089		41.914	
RM2				3.197		42.806	
CE = 42.806 - 42.806 = 0.000 CE limit = $10.003 * (\sqrt{2setup}) = 10.004$							
0 ft mark on clamped tape is 3.373 ft gage datum							
Tape	22.409		25.782			3.373	Direct read
ETG _{index}				0.873		24.909	
TP2	6.234		26.365	5.651		20.131	Moved Inst
ETG _{index}				1.456		24.909	
Tape				22.992		3.373	Direct read
CE = 3.373 - 3.373 = 0.000 CE limit = $10.003 * (\sqrt{2setup}) = 10.004$							
Tape	6.061		9.434			3.373	Direct read
RM1				2.328		7.106	Bolt E side Rt Pier
ETG _{weight}				0		9.434	@ HI
RP1				3.231		6.203	Nail @ 6.20 ft
WS	@ 10:15			8.008		1.426	ETG(ref) = 1.43, WM=1.43
WM _{bottom}				0		9.434	@ HI
TP3	7.043		9.568	6.909		2.525	Moved Inst
WM _{bottom}				0		9.568	@ HI
WS	@ 10:20			8.142		1.426	ETG(ref) = 1.43, WM=1.43
RP1				3.365		6.203	nail @ 6.20 ft
ETG _{weight}				0		9.568	@ HI
RM1				2.462		7.106	
Tape				6.195		3.373	Direct read
CE = 3.373 - 3.373 = 0.000 CE limit = $10.003 * (\sqrt{2setup}) = 10.004$							

B

Figure 27. Continued.

CLOSURE- ERROR ADJUSTMENT TO HI	ADJUSTED 1 st ELEVATION	ADJUSTED 2 nd ELEVATION	DIFFERENCE (AE1 -AE2)	FINAL ELEVATION	OLD ELEVATION	Remarks
0.0000					7.106	Given, Origin
	9.434					ETG reads 9.43
	6.203		0.000	6.203	6.203	
	3.373		0.000	3.373		Bottom of clamped tape
	1.426					+/-0.01, DCP=1.43
	9.434					WW reads 9.43
0.0000						
		9.568				WW reads 9.57
		1.426				+/-0.01, DCP=1.43
		3.373				
		6.203				
		9.568				ETG reads 9.57
0.0000	24.909		0.000	24.909	24.909	Given
0.0000		24.909				
0.0000	44.741		0.000	44.741	44.741	Given
	42.806		0.000	42.806	42.806	Check bar reads 44.74
	41.914		0.000	41.914	41.914	
0.0000						
		41.914				
		42.806				
		44.741				Check bar reads 44.74

OBJECT	BS	CORRECTED BS BS+(CTE* BS*(T-T ₀))	HEIGHT OF INSTRU- MENT (HI)	FS	CORRECTED FS FS+(CTE* FS*(T-T ₀))	ELEVATION	Remarks
RM1	2.328		9.434			7.106	Bolt E side Rt Pier
ETG _{in} read				0		9.434	@ HI
RP1				3.231		6.203	nail @ 6.20 ft
Tape				6.061		3.373	Direct read
WS	@ 10:15			8.008		1.426	ETG (ref)=1.43, WW=1.43
WW _{bottom}				0		9.434	@ HI
TP1	7.043		9.568	6.909		2.525	Moved Inst
WW _{bottom}				0		9.568	@ HI
WS	@ 10:20			8.142		1.426	ETG (ref)=1.43, WW=1.43
Tape				6.195		3.373	Direct read
RP1				3.365		6.203	
ETG _{in} read				0		9.568	@ HI
RM1				2.462		7.106	
CE = 7.106 - 7.106 = 0.000 CE Limit = 10.003*($\sqrt{2}$ setup) = 10.004							
Bottom of tape = 3.373							
Tape	22.409		25.782			3.373	Direct read
ETG _{in} read				0.873		24.909	
TP2	6.234		26.365	5.651		20.131	Moved Inst
ETG _{in} read				1.456		24.909	
Tape				22.992		3.373	Direct read
CE = 3.373 - 3.373 = 0.000 CE Limit = 10.003*($\sqrt{2}$ setup) = 10.004							
Tape	42.843		46.216			3.373	Clamped @ 40', rod=2.843
WWC8				1.475		44.741	
RM2				3.410		42.806	Brass cap right abutment
RM4				4.302		41.914	Brass cap on sidewalk 75N
TP3	2.682		46.003	2.895		43.321	Moved Inst
RM4				4.089		41.914	
RM2				3.197		42.806	
WWC8				1.262		44.741	
Tape				42.630		3.373	Clamped @ 40', rod=2.630
CE = 3.373 - 3.373 = 0.000 CE Limit = 10.003*($\sqrt{2}$ setup) = 10.004							

C

Figure 27. Continued.

Bridge-Down Method

The diagram in [figure 27](#) shows a weighted steel tape clamped at its 40.000-ft marking to the bridge deck rail. The first level circuit is on the bridge deck and the objective points are RM2, RM4, the wire-weight check bar, and the clamped steel tape (noted as “tape” in the level notes). RM2 is the origin and is used to establish the initial instrument height. Foresights are taken on the wire-weight check bar and the bridge deck rail where the tape is clamped. The FS to the top of the deck rail at the tape is 2.843 ft, noted in the remarks column in the level notes. The tape is being used as a long leveling rod; therefore, the FS to the rod at the tape, 2.843 ft, is added to the suspended length of the tape, 40.000 ft, to get the representative FS, 42.843 ft. An independent turning point, TP1, is established and a second instrument height is determined from which second FSs are taken on the tape, wire-weight check bar, and RM4. The circuit associated with the bridge deck is completed by taking a second FS on the origin, RM2. The first and second elevations of the 0.000-ft mark on the suspended tape are determined by subtracting the representative FSs for the tape from the instrument height. Both representative FSs for the tape are used to determine that the elevation at the 0.000-ft mark on the suspended tape is 3.373 ft. The closure error for this circuit is 0.000 ft, elevations do not need to be adjusted, and the differences between first and second elevations for all of the objective points are 0.000 ft.

A second level circuit is about half the distance from the bridge deck to the low-water bank, and the objective points are the tape and the ETG index. The instrument height is established with a BS taken on the tape, which is a direct read of 22.409 ft. This BS is added to the determined elevation for the 0.000-ft mark of the tape, 3.373 ft, to determine an instrument height of 25.782 ft. A FS is taken on the ETG index and an independent turning point, TP2, is established to determine the second instrument height. A second FS is taken on the ETG index and this circuit is completed by taking a second FS on the suspended tape, which again is a direct read of the tape. This circuit has a closure error of 0.000 ft, elevations do not need to be adjusted, and the difference between first and second elevations for the ET index is 0.000 ft.

The final level circuit is on the low-water bank and the objective points are the tape, RM1, the bottom of the electric tape weight (ETG weight), RP1, the water surface, and the bottom of the wire weight (noted as “WW bottom” in the level notes). Again, the instrument height is established with a BS taken on the tape, which is a direct read of 6.061 ft. This BS is added to the determined elevation for the 0.000-ft mark of the tape, 3.373 ft, to determine an instrument height of 9.434 ft. From this instrument height, first FSs are taken on RM1, the ETG weight through the cleanout door, RP1, the water surface, and the bottom of the wire weight near the water surface. An independent turning point is established, TP3, to determine the

second instrument height from which second FSs are taken. This final circuit is completed by taking a second FS on the suspended tape. This circuit has a closure error of 0.000 ft, elevations do not need to be adjusted, and differences between first and second elevations for each of the objective points are 0.000 ft. By using a weighted suspended steel tape clamped to the bridge deck rail to carry elevation from the bridge down to the low-water bank, levels can be run at a gaging station with an elevation difference of over 35 vertical ft using three sequentially closed level circuits that have a total of six instrument setups and three turning points.

Ground-Up Method

The ground-up method reverses the procedure for the bridge-down method and begins from the low-water bank. A weighted steel tape is clamped at its 40.000-ft marking to the bridge deck rail. The first level circuit is on the low-water bank and the objective points are RM1, the bottom of the electric tape weight (ETG weight), RP1, the steel tape, the water surface, and the bottom of the wire weight. The initial instrument height is established with a BS taken on RM1. Foresights are taken on the ETG weight through the cleanout door, RP1, the steel tape, the water surface, and the bottom of the wire weight near the water surface. An independent turning point is established, TP1, to determine the second instrument height from which second FSs are taken on the objective points. The circuit is completed by taking a final FS on the origin, RM1. The elevation of the 0.000-ft mark on the suspended tape is determined by subtracting the FSs for the tape from the associated instrument heights. Both FSs taken on the tape determined that the elevation of the 0.000-ft mark on the suspended tape is 3.373 ft. The closure error of this circuit is 0.000 ft, elevations do not need to be adjusted, and the differences between first and second elevations for all of the objective points are 0.000 ft.

A second level circuit is about half the distance from the low-water bank to the bridge deck, and the objective points are the tape and the ETG index. The instrument height is established with a BS taken on the tape, which is a direct read of 22.409 ft. This BS is added to the determined elevation for the 0.000-ft mark of the tape, 3.373 ft, to determine an instrument height of 25.782 ft. A FS is taken on the ETG index and an independent turning point, TP2, is established to determine the second instrument height. A second FS is taken on the ETG index and this circuit is completed by taking a second FS on the suspended tape, which again is a direct read of the tape. This circuit has a closure error of 0.000 ft, elevations do not need to be adjusted, and the difference between first and second elevations for the ETG index is 0.000 ft.

The final level circuit is on the bridge deck and the objective points are the steel tape, wire-weight check bar, RM2, and RM4. The instrument height is established with a BS of 2.843 ft, taken on the top of the deck rail at the tape,

and noted in the remarks column in the level notes. The tape is being used as a long leveling rod; therefore, the BS to the rod at the tape is added to the suspended length of the tape, 40.000 ft, to get the representative BS, 42.843 ft. The determined elevation for the 0.000-ft mark of the tape, 3.373 ft, is added to the BS to determine an instrument height of 46.216 ft. From this instrument height, first FSs are taken on the wire-weight check bar, RM2, and RM4. An independent turning point, TP3, is established and a second instrument height is determined from which second FSs are taken on RM4, RM2, and the wire-weight check bar. The circuit associated with the bridge deck is completed by taking a second FS on the deck rail at the tape. The closure error for this circuit is 0.000 ft, elevations do not need to be adjusted, and the differences between first and second elevations for all of the objective points are 0.000 ft. By using a weighted suspended steel tape clamped to the bridge deck rail to carry elevation from the low-water bank to the bridge deck, levels can be run at a gaging station with an elevation difference of over 35 vertical ft using three sequentially closed level circuits that have a total of six instrument setups and three turning points.

Office Procedures

The task of running levels at gaging stations includes some important office-related activities. A final check of the computations made during the level run that were first checked in the field should be made and documented. Following a level run, any adjustments made to the elevation of the reference gage need to be applied to the time series record of gage height and any other affected measurements of the reference gage. The field notes, which include digital files, original hand written documents, and photographs taken during field work, should be stored according to office specifications. The historical level summary and station description should be updated to reflect the elevations found during the level run. Finally, if needed, the site sketch should be updated along with any descriptions of reference marks that may have changed or been added since the last level run.

Applying Datum Corrections to Gage Height Time Series

The primary reference gage at a continuously recording gaging station is used to set the gage height on the data logger and to determine the representative gage heights for discharge measurements. If the level run finds that the absolute value of the difference between the elevation reading of the reference gage and the gage datum is greater than or equal to 0.015 ft, the recorded stage record must be corrected. Corrections of this type are referred to as datum corrections. Similarly,

observed gage height measurements made during the time period affected by the datum correction should be adjusted accordingly. The datum correction applied to the time series of recorded stage values should be applied in a manner that is consistent with what caused, or was assumed to cause, the reference gage elevation to be different from the gage datum. For example, if the reference gage is damaged during a flood, the datum correction should be applied at the time the damage occurs and held constant until the time levels are run and the reference gage is adjusted. If the reference gage is assumed to have been heaved by frozen ground during the winter, the datum correction should be held constant back to the winter period. If the gage remains ice-free during the winter and it is believed the reference gage was heaved slowly during the winter, the datum correction may then be prorated back through the winter period.

Developing a Site-Specific Historical Level Summary

A historical level summary that contains the final elevations of all objective points from every level run should be maintained for all gaging stations. The level summary also should contain descriptions of all reference marks, reference points, and gages. Other objects of interest that were shot during a level run, such as the gage height of zero flow or the orifice line terminus, can also be included in the level summary. The primary reference gage should be explicitly noted. The level summary provides a way to track elevations and thus, vertical stability of all objective points over the life of the station. The stage that each of the various gages at the station was found to be reading at the beginning of a level run should be noted as well as the stage each gage was reading at the end of a level run. The origin reference mark for each of the level runs should be noted. The historical level summary should be updated immediately every time levels are run at the gaging station. A digital summary file provides the best means for storage and retrieval and can easily be updated. A form template for the historical level summary for printing or download is provided in [appendix D](#).

Developing a Site Sketch Map

A sketch map of the site will help anyone who runs levels at the station. This is especially true for someone who is unfamiliar with a particular station. This map should show the locations of the reference marks, reference points, and all gages with respect to the gaging station structure and other prominent objects. The location of the low-water control along with the direction of flow should be included. Recommended instrument setup locations that provide ideal shot distances are useful as well. Site sketch maps are best maintained and stored in digital format.

Auxiliary Data to be Obtained During Level Runs

Running levels at gaging stations provides an opportunity to acquire other useful elevation-related information. Fresh high-water marks, if present, should be surveyed and compared later to recorded gage heights. A cross section of the hydraulic control(s) (including section, channel, and bank-full elevations), surveyed in the gage datum, is easy to obtain and can aid in developing the stage-discharge rating for the site. The gage height of zero flow associated with the hydraulic control that defines the low-water stage-discharge relation can be easily measured when the instrument is set up to measure the water-surface elevation during levels. Documenting the elevation, or gage height, at which flow overtops either bank can assist the USGS and other agencies during flood conditions. Determining the minimum elevation of a bridge or road deck in the gage reach can be very useful during flood events. Measurements of the elevations of various gage components, such as the orifice line terminus or stilling well intakes, can assist in determining the gage height at which the gage is out of communication with the stream. A measurement of the elevation of the instrument shelf provides an estimate of the likely maximum gage height the data logger can record. In short, the efficiency with which engineer's levels can obtain accurate vertical measurements presents opportunities to acquire auxiliary data when running levels at gaging stations.

Summary

Levels are run at gaging stations to ensure gages are accurately set to the established gage datum. Differential leveling techniques are used to determine elevations for reference marks, reference points, all gages, and the water surface to a precision of 0.001 foot (ft). Desired accuracy for a set of station levels is less than 0.010 ft. Precision describes the closeness of one measurement to another while accuracy describes how close a given measurement is to the true value. The techniques presented in this manual provide guidance on instruments and methods that ensure gaging-station levels are run to both a high precision and accuracy.

Levels are run at gaging stations whenever unresolved gage reading differences are identified, damage is suspected to have occurred to the station, or according to a frequency recommended for a given station. Engineer's levels, optical levels and electronic digital levels, are commonly used for running levels at gaging-stations. Collimation tests should be run at least once during any week that levels are run. Collimation error for an instrument cannot exceed the absolute value of 0.003 ft/100 ft. Instruments exceeding this collimation tolerance should be adjusted, and another

collimation test must be run before it is used for gaging-station levels. If an instrument fails a collimation test, all levels run since the prior passing collimation test cannot be used and must be re-run.

An acceptable set of gaging-station levels consists of a minimum of two foresights, each from a different instrument height, to at least two independent reference marks, all reference points, all gages, and the water surface. The initial instrument height is determined from a third independent reference mark, known as the origin, or base reference mark. The absolute value of the closure error of a leveling circuit must be less than or equal to $0.003\sqrt{n}$ ft, where n is the total number of instrument setups. The entire level circuit must be re-run if closure error exceeds this threshold; closure error may not exceed |0.015| ft, regardless of the number of instrument setups. Closure error for a leveling circuit is distributed by instrument setups in a manner that assumes error accumulates linearly and elevations for objective points are adjusted accordingly. Absolute differences between the adjusted first and second elevations for the objective points in the circuit must be less than or equal to 0.005 ft. Objective points with absolute differences between adjusted first and second elevations exceeding 0.005 ft require two more foresights from different instrument heights. Final elevations of objective points are determined by averaging the valid adjusted first and second elevations. Reference gages should be reset if the absolute value of the difference between the elevation reading of the reference gage and the gage datum is greater than or equal to 0.015 ft. A summary of selected requirements and tolerances for gaging-station levels is provided in [appendix E](#).

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Glossary

Backsight (BS). The reading on a leveling rod held on a point of known elevation that is used to establish a height of an instrument.

Benchmark . A permanent marker with known survey control of vertical and (or) horizontal coordinates in an established geodetic system, such as the North American Vertical Datum of 1988.

Closure error. The difference between the elevation of the starting point, or origin, of a closed level circuit and the elevation of that same point from the final instrument setup; computed as the given elevation minus the final elevation.

Collimation. Agreement of a surveying instrument's line of sight with its horizontal axis.

Collimation error. The deviation or inclination of a level's line of sight from horizontal, often given in a vertical deviation per horizontal distance such as feet per 100 feet; positive when the line of sight points downward from the instrument.

Curvature and refraction effect. The increase in a leveling rod's reading caused by the combination of the Earth's curvature and atmospheric refraction effects.

Datum. A level surface that represents zero elevation.

Differential leveling. The determination of the difference in elevation of two points using a surveying instrument and a leveling rod.

Elevation. The vertical distance from a point to the datum.

Engineer's level. A surveying instrument consisting of a minimum of a telescopic sight and a sensitive leveling device to make the line of sight horizontal.

Optical level. An engineer's level that is used to manually read a leveling rod.

Electronic digital level. An engineer's level with an automated system that reads a leveling rod.

Foresight (FS). The reading on a leveling rod held on a point whose elevation is to be determined.

Gage datum. The zero elevation reference surface at a gaging station to which all gages are set.

Gage height. The elevation of the water surface at a gaging station, used interchangeably with stage.

Gage height of zero flow. The gage height at which streamflow ceases. Associated with the elevation of the lowest point on the low-water hydraulic control of a gaging station.

Gaging-station levels. Differential levels run (that is, carried out) at a gaging station to define and maintain a constant gage datum for all gages.

Height of instrument (HI). The elevation of the horizontal line of sight of a surveying instrument.

Horizontal. A direction that is perpendicular to the force of gravity.

Parallax. The relative movement of the image of a leveling rod with respect to the cross hairs of a surveying instrument as the observer's eye moves, caused by improper focusing of the objective lens of the instrument.

Reference mark (RM). A permanent marker, installed in the ground or on a structure, whose elevation above a set datum is known. Used to check and make sure that all gages and reference points are properly set to gage datum.

Reference point (RP). Objects, often bolts or screws that are assigned an elevation in the gage datum. Used to obtain gage heights when necessary by measuring their distance to the water surface.

Stage. The elevation of the water surface at a gaging station, used interchangeably with gage height.

Temporary reference mark (TRM). A temporary point of reference that was treated as an objective point in a previously closed level circuit that is used to carry elevations to other instrument setups.

Turning point (TP). A temporary point of reference in an open level circuit that is used to carry elevations to other instrument setups in the level circuit.

Vertical. The direction of the force of gravity.

Appendix A. Fixed-Scale Test Form

FIXED SCALE COLLIMATION TEST OF ENGINEER'S LEVEL

Tested by: _____ Date: _____

Make/Model: _____ Circle system type(s): ☐ optical ☐ digital

$$\text{Collimation} = c = 100 * \left[\frac{(R_1 - R_2)}{(d_2 - d_1)} \right]$$

d_2 should be less than 110 ft.

OPTICAL SYSTEM			R	d
$c = 100 * \left[\frac{(\quad - \quad)}{(\quad - \quad)} \right]$ c = _____ ft/100ft as found	1			
	2			

DIGITAL SYSTEM			R	d
$c = 100 * \left[\frac{(\quad - \quad)}{(\quad - \quad)} \right]$ c = _____ ft/100ft as found	1			
	2			

ADJUSTMENT (level remains set up at ORIGINAL LOCATION)

To adjust level, set R_2 to read R_1 $R_1 =$ _____ System adjusted: ☐ optical ☐ digital

To test collimation after adjustment, set up near other scale and repeat measurements.

$c = 100 * \left[\frac{(\quad - \quad)}{(\quad - \quad)} \right]$		R	d
	1		
	2		

NOTES or COMMENTS:

Appendix B. Peg Test Form

PEG TEST OF ENGINEER'S LEVEL

Tested by: _____
Date: _____

Make/Model: _____
Circle system type(s): optical digital

$$\text{Collimation} = c = 100 * \left[\frac{(R_1 + R_3) - (R_2 + R_4)}{(d_2 + d_4) - (d_1 + d_3)} \right]$$

Average of d₂ and d₄ should be less than 110 ft.

OPTICAL SYSTEM		R	d
$c = 100 * \left[\frac{\left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right) - \left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right)}{\left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right) - \left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right)} \right]$ c = _____ ft/100ft as found	1		
	2		
	3		
	4		

DIGITAL SYSTEM		R	d
$c = 100 * \left[\frac{\left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right) - \left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right)}{\left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right) - \left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right)} \right]$ c = _____ ft/100ft as found	1		
	2		
	3		
	4		

ADJUSTMENT (level remains set up at 2 and sighted at R₄)

Adjust cross hair to $R_4 \pm \left[\frac{(cd_4)}{100} \right] = \text{_____} \pm \left[\frac{(\text{_____})}{100} \right]$

Repeat collimation test after adjustment.

COLLIMATION TEST AFTER ADJUSTMENT

$$c = 100 * \left[\frac{\left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right) - \left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right)}{\left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right) - \left(\begin{smallmatrix} + \\ + \end{smallmatrix} \right)} \right]$$

c = _____ ft/100ft as found

NOTES or COMMENTS:

(Full-size form [8" x 10"] is available for download at <http://pubs.usgs.gov/tm/tm3A19>)

[illegible]

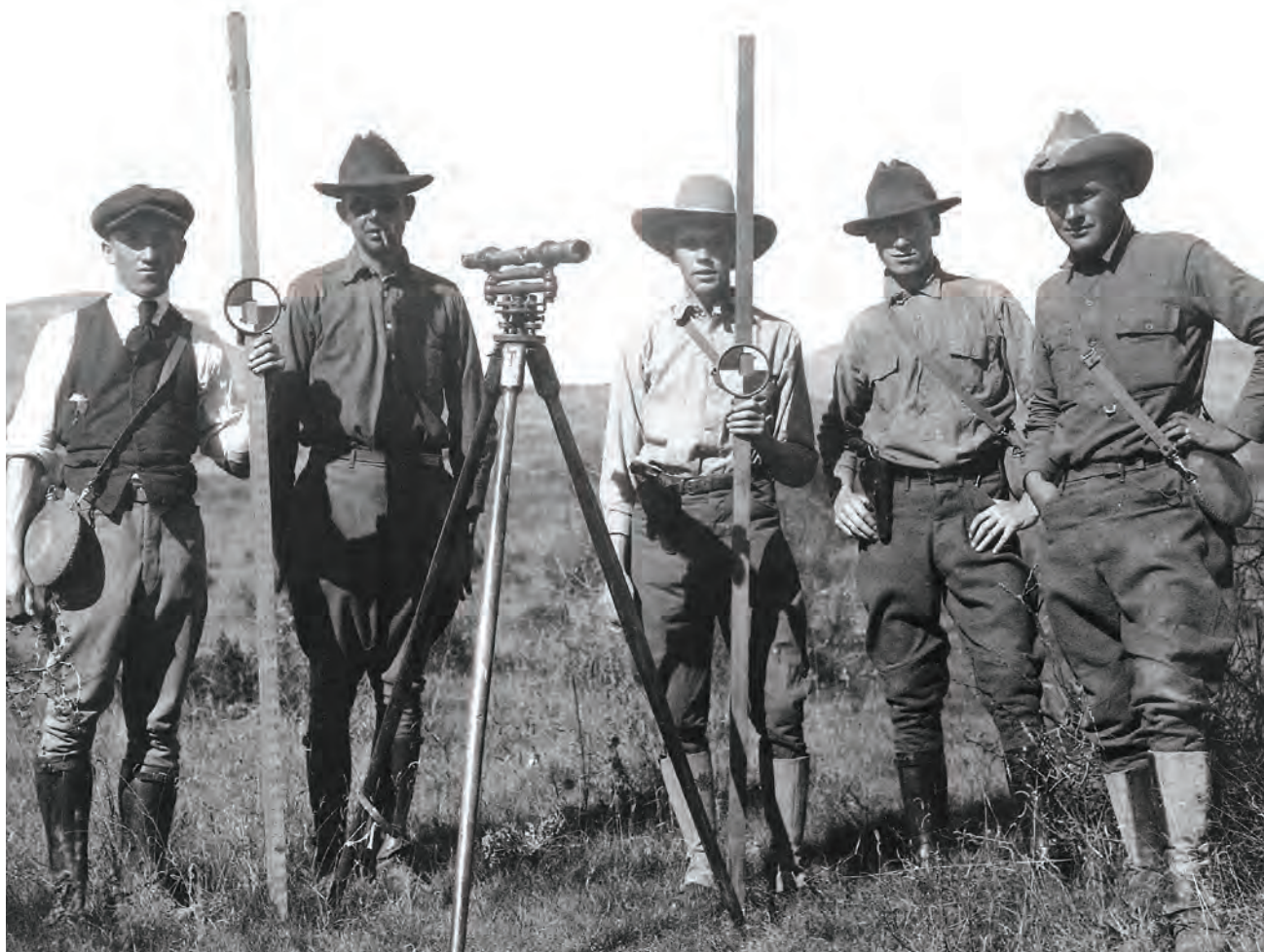
Appendix E. Summary of Selected Requirements and Tolerances for Gaging Station Levels

[n is the number of instrument setups in level circuit. ft, foot; <, less than; | |, absolute value]

Requirements and tolerances	
Precision of gaging station levels	0.001 ft
Accuracy of gaging station levels	<0.01 ft
Maximum number of days since the last collimation test	7
Maximum collimation error of level instrument	$ 0.003 \text{ ft}/100 \text{ ft}$
Maximum allowable difference between rod scale and tape check	$ 0.002 \text{ ft}$
Minimum number of reference marks in a level run	3
Maximum temperature correction, C_t , computed using maximum vertical distance from origin (equation 3) that does not require correcting all shots for thermal expansion or contraction	$ 0.003 \text{ ft}$
Maximum allowable closure error	$ 0.003\sqrt{n} $ and not to exceed $ 0.015 \text{ ft}$
Minimum number of foresights to	
at least two reference marks	2
all reference points	2
all gages	2
the water surface	2
the origin reference mark	1
Minimum number of non-objective point turning points	1
Maximum allowable difference between the adjusted first and the adjusted second elevations of objective points	$ 0.005 \text{ ft}$
Maximum allowable difference between the elevation reading of the reference gage and the gage datum	$< 0.015 \text{ ft}$

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<http://water.usgs.gov/osw/>



ATTACHMENT D
NW NATURAL, GASCO, ADDITIONAL
GROUNDWATER FLOW ANALYSIS,
SS PAPADOPULOS, 2008



S.S. PAPADOPULOS & ASSOCIATES, INC.
ENVIRONMENTAL & WATER-RESOURCE CONSULTANTS

Memorandum

Date: April 25, 2008
From: Michael J. Riley
To: John Edwards
Subject: **NW Natural, Gasco: Additional Groundwater Flow Analysis**

On behalf of Anchor Environmental, LLC (Anchor), S.S. Papadopoulos & Associates, Inc. (SSPA) prepared the memorandum *NW Natural Gasco, Pump Test Analysis and MODFLOW Model Summary* (SSPA, October 30, 2007). The 2007 Model Summary was in Appendix E of the *Groundwater/DNAPL Source Control Focused Feasibility Study, NW Natural GASCO Site* (Anchor, November, 2007). At a January 24, 2008 meeting with DEQ, NW Natural was asked to further evaluate three issues related to the 2007 Model summary.

- Develop model with an alternative hydrogeologic CSM in which the deeper alluvial sand with a higher hydraulic conductivity extends upgradient until it intercepts bedrock
- Reality check on estimate of upgradient groundwater flow into model
- Evaluation of “zero” drawdown in MW-05-175

In a letter from Oregon DEQ dated March 21, 2008, NW Natural was asked to further evaluate five issues listed below.

1. Additional documentation that basalt is a no flow boundary
2. Using independent methods to confirm total groundwater flux
3. Explain contradiction between rapid draw down in PW-04 and complete capture conclusion
4. Evaluate increase in hydraulic conductivity with depth as cause of above
5. Provide hydraulic property assignments not previously provided

Items 1 and 5 have been addressed with a recent revision of the NW Natural Gasco, Pump Test Analysis and MODFLOW Model Summary (April, 2008).

The three bullet items identified by DEQ in the January 24 meeting, and items 2, 3, and 4 identified in the March 21 letter, are further evaluated and answered in this memorandum *Additional Groundwater Flow Analysis*.

This memo presents results from a number of analyses conducted in response to the above issues raised by DEQ. These analyses include:

- Evaluation of hydraulic conductivity from grain size data at MW-18, MW-19, and MW-20
- Interpolation of seepage rate from seepage meters
- Modification of the groundwater flow model
- Groundwater model simulation of PW-4-85 and PW-4-118 pump test.

Grain Size Analysis

Grain size data from MW-18, MW-19, and MW-20 were used to compute hydraulic conductivity values using methods developed by Hazen and Shepherd presented in Fetter (1994)¹. Hazen developed a formula based on the D_{10} of the grain size distribution, which is a measure of the finest 10 percent particle sizes. Shepherd based his analysis on the D_{50} size. Both follow the same general formula:

$$K = CD_i^j$$

Where: K is hydraulic conductivity
C is a coefficient
D is a representative particle size, i (10 percentile for Hazen and 50 for Shepherd)
 j is an exponent (2 for Hazen and varies from 1.5 to 2 for Shepherd)

Both methods are somewhat subjective as the coefficient is estimated based on how well sorted the sample is and other subjective factors. For Shepherd, the exponent as well as the coefficient must be estimated.

Hazen's use of D_{10} as the representative particle size results in very low estimates for hydraulic conductivity at the site since many of the samples contain 10% silt and clay size particles, however the average grain size is significantly larger. As a result, more reasonable values were computed using the Shepherd formulation. For the analysis, the shallow alluvium was represented as channel deposits (less well sorted) and the deeper alluvium was treated as beach deposits (more sorted). Results of this analysis are presented in the following tables.

MW-18	Depth (ft bgs)	D_{50} (inches)	K (ft/d)	
			Channel Deposits ¹	Beach Deposits ²
	30	0.0037	9.1	25.7
	40	0.0438	537	1930
	50	0.0002	0.05	0.09
	60	0.0028	5.9	16.0

¹ Fetter, C. W. 1994 Applied Hydrogeology. Third edition. Prentice-Hall, Inc. Upper Saddle River, NJ

70	0.0019	3.1	8.1
80	0.0042	11.0	31.3
90	0.0020	3.3	8.8
100	0.0063	22.0	65.2
110	0.0075	28.9	87.1
120	0.0076	29.6	89.3
130	0.0062	21.3	62.9
140	0.0044	12.3	35.2
150	0.0033	7.6	21.0
160	0.0038	9.3	26.3
170	0.0064	22.4	66.5
180	0.0055	17.5	51.3

1) C = 450; j = 1.65

2) C = 1600; j = 1.75

MW-19		K (ft/d)	
Depth (ft bgs)	D ₅₀ (inches)	Channel Deposits ¹	Beach Deposits ²
30	0.0029	6.0	16.4
40	0.0035	8.4	23.5
50	0.0017	2.6	6.7
60	0.0001	0.04	0.07
70	0.0001	0.03	0.07
80	0.0044	12.1	34.5
90	0.0057	18.3	53.6
100	0.0001	0.04	0.09
110	0.0074	28.7	86.4
120	0.0073	27.8	83.4
130	0.0070	26.1	78.1
140	0.0036	8.7	24.2
150	0.0127	69.9	222
160	0.0034	8.0	22.3
170	0.0065	23.1	68.7
180	0.0070	26.3	78.6

1) C = 450; j = 1.65

2) C = 1600; j = 1.75

MW-20		K (ft/d)	
Depth (ft bgs)	D ₅₀ (inches)	Channel Deposits ¹	Beach Deposits ²
30	0.0025	4.6	12.5

40	0.0037	8.9	25.0
50	0.0001	0.03	0.06
60	0.0043	11.5	32.8
70	0.0037	9.2	26.0
80	0.0057	18.5	54.1
90	0.0001	0.03	0.06
100	0.0001	0.03	0.07
110	0.0075	28.9	87.0
120	0.0072	27.4	82.2
130	0.0056	17.8	52.1
140	0.0065	23.2	68.8
150	0.0053	16.6	48.3
160	0.0044	11.9	34.0
170	0.0036	8.5	23.8
180	0.0064	22.4	66.3

1) $C = 450, j = 1.65$ 2) $C = 1600; j = 1.75$

The analysis shows a distinct break between less permeable material above 100 ft bgs and more permeable material with depth. The less permeable material corresponds to the depth of material defined as shallow alluvium in the Gasco site groundwater flow model. The hydraulic conductivity value of 10 ft/d used in the model is similar to the values computed here. The grain size analysis for deeper alluvium, although higher in hydraulic conductivity, is not as high as the 300 ft/day used in the model. The higher hydraulic conductivity in the model will produce a higher groundwater flow rate and therefore is a more conservative choice of parameters than the deep alluvium hydraulic conductivity presented here.

Seepage Analysis

Seepage meter data collected in sediments offshore from the Gasco site shows a range of values. The variability in seepage rates is likely due to differences in hydraulic conductivity of the interbedded shallow alluvial sands and silts. Several methods were used to assign seepage meter data to offshore areas. In the present analysis, the location of the seepage meters were digitized and a sector grid extending 3 sectors offshore and 10 sectors along shore was used to interpolate the seepage results to offshore areas. The interpolation used kriging to project the seepage meter data to the center of each sector. Both linear and exponential kriging were used. The linear kriging interpolation produced a seepage rate of 225 gpm and the exponential kriging produced a seepage rate of 253 gpm. Both agree favorably with upgradient boundary flows extrapolated from the U.S.G.S. Portland Basin model of approximately 200 gpm. The seepage analysis is further described in Section 4.4 of the *Offshore Investigation Report, NW Natural Gasco Site* (Anchor, February, 2008)

Modification of the Groundwater Flow Model

The groundwater flow model was modified in two ways:

- The high hydraulic conductivity zone in the deep alluvium was extended upgradient to the basalt contact
- The hydraulic conductivity of the shallow alluvium was modified to determine how this affects the upgradient boundary flow.

Previously, the high hydraulic conductivity zone of the deep alluvium was limited to an area between the pilot boring wells and the river. In the modified model, this zone was extended throughout the deep alluvium. Based on the grain size analysis of MW-18, MW-19 and MW-20 presented above, 100 ft bgs (elevation of approximately -70 feet) was used to extend the deep alluvium hydraulic conductivity to bedrock in the upgradient direction. That is, the deep alluvium below an elevation of -70 ft was set to a hydraulic conductivity of 300 ft/d. This resulted in an increase in upgradient boundary flow from 154 gpm to 172 gpm.

The shallow alluvium was previously set with a hydraulic conductivity value of 10 ft/d. This value agrees with the average value for the shallow alluvium in the grain size analysis, if the very low values and the extremely high value at MW-18-40 are not used. However, as a sensitivity analysis, the shallow alluvium hydraulic conductivity was increased to 15 ft/d. This change was made with the high hydraulic conductivity zone of the deep alluvium extending to bedrock as described above. Changing the hydraulic conductivity of the shallow alluvium resulted in an increase in the upgradient boundary flow from 172 gpm to 245 gpm.

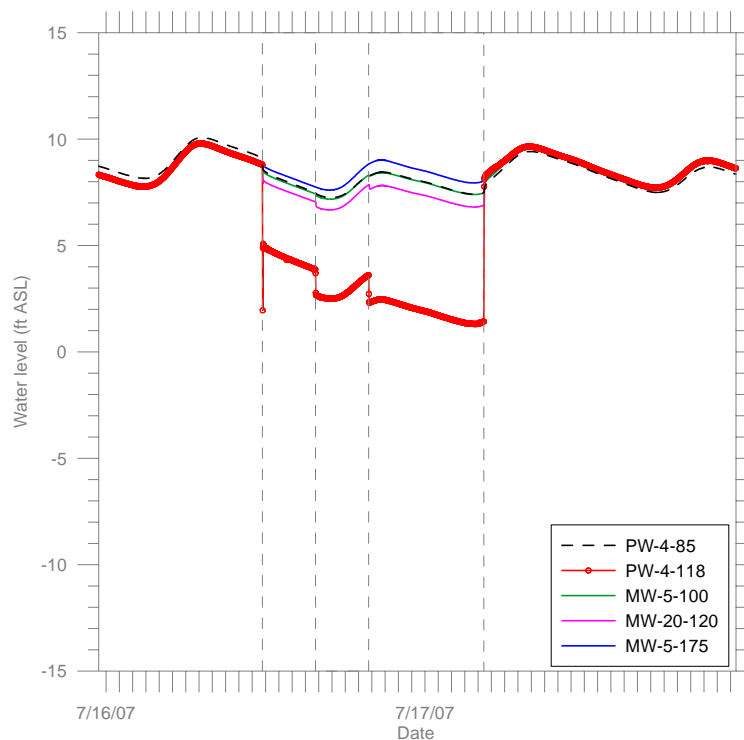
Increasing the hydraulic conductivity of the shallow alluvium and extending the high hydraulic conductivity zone of the deep alluvium to all of the deep alluvium increases the boundary flow closer to the value estimated with the U.S.G.S. model. Higher boundary flow rates can be reached by increasing the hydraulic conductivity of the shallow alluvium. While the original value of 10 ft/d agrees well with pump test analysis and grain size analysis, representing a higher flow rate in the model is more conservative with respect to capture zone design as it will result in higher design pump rates for a groundwater extraction system. Therefore, it is recommended to use a hydraulic conductivity of 15 ft/d for the shallow alluvium in design-related simulations.

Simulation of PW-4 Pump Test

In the analysis of the PW-4-118 step test (Anchor, November, 2007), a simplifying assumption was made that water levels at MW-5-175 were not affected by the pumping. This raised a

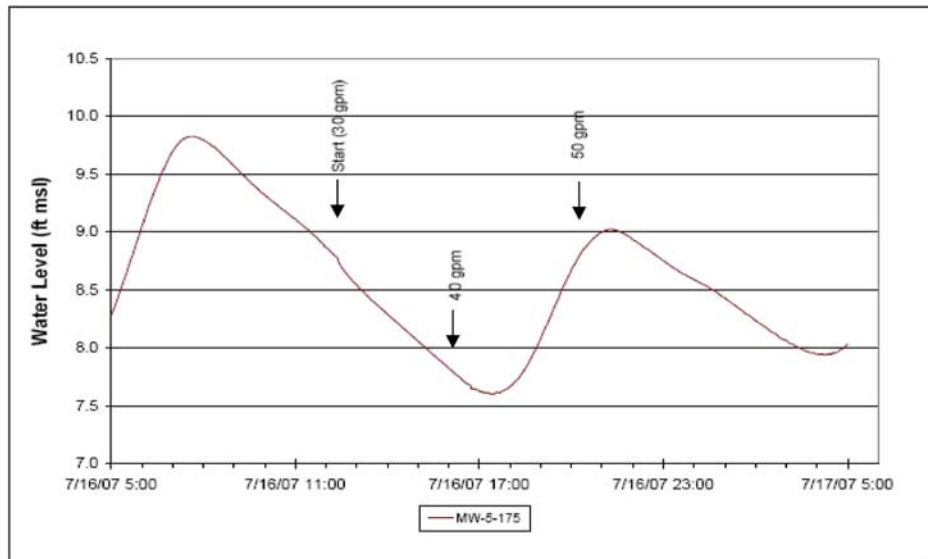
concern from DEQ that a high flow interval between the screen of the pumping well and MW-5-175 may prevent capture of groundwater in the vicinity of this well.

The measured water level data at MW-5-100, MW-5-175 and MW-20-120 during the PW-4-118 step test are shown in the following figure. During that test, PW-4-118 was pumped at three steps with discharge rates of 30, 40, and 50 gpm.

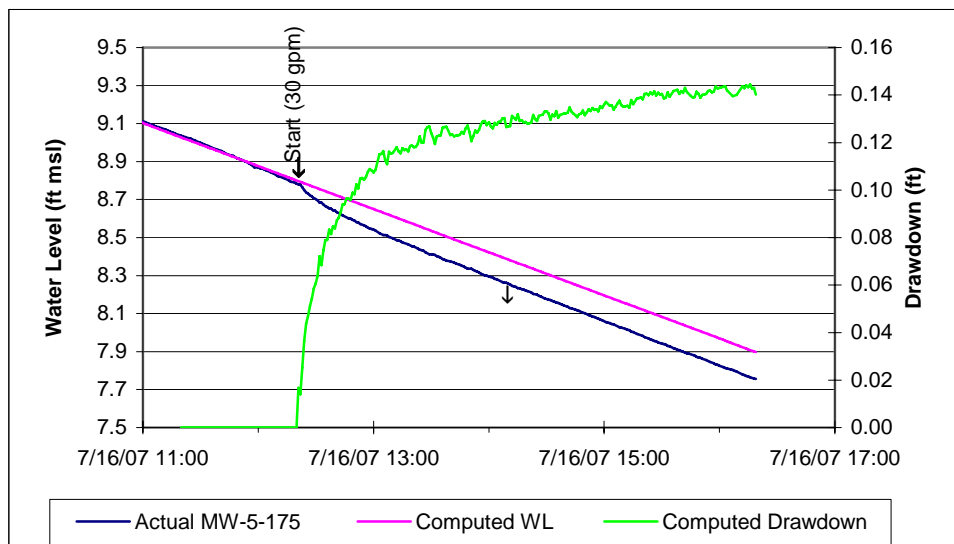


At the scale shown above, the water level at MW-5-175 appears to be unaffected by pumping. Consequently, the water levels at MW-5-175 were used to compute drawdown for the other wells. A closer examination of the water levels at MW-5-175 is shown in the following figure.

Page 7



The first step shows a very slight change in water level, but the second and third steps are too close to the low and high tide level to discern a change in water level. To compute drawdown, water levels prior to the start of the test (from 9:00 to 12:15) were extrapolated by linear regression through the first step (from 12:20 to 16:20). The measured and computed water level and drawdown are shown on the following graph.

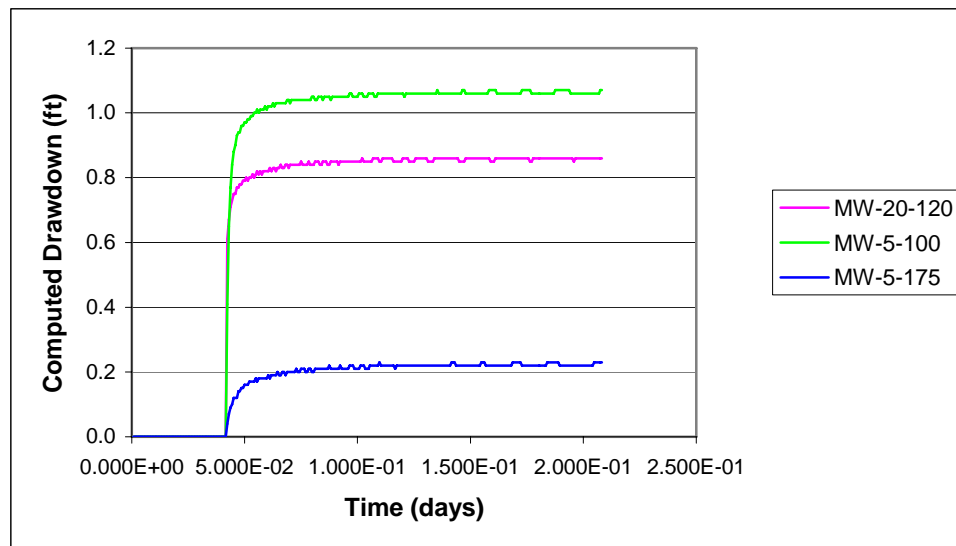


Computed drawdown levels off at about 0.14 ft. The slow steady increase in drawdown from 0.12 to 0.14 ft is a result of extrapolating the computed water level. Taking drawdown as linear with pump rate, the drawdown at 50 gpm would be approximately 0.20 to 0.23 ft. Although the

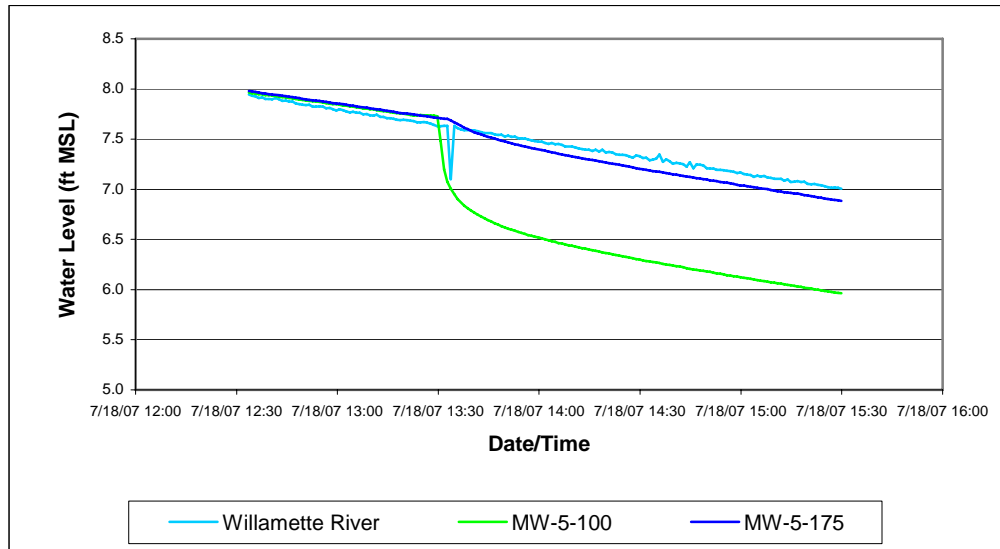
PW-4-118 step drawdown analysis was based on an assumption of zero drawdown at MW-5-175, the actual drawdown of 0.20 to 0.23 ft is small enough that it does not significantly affect the findings of the pump test analysis described in Appendix E of the 2007 Model Summary.

For this modeling analysis, the model was set up to simulate the PW-4-85 and PW-4-118 combined constant rate test conducted September 18, 2007. This test was selected because the higher pump rate and the dual pumping wells provide a greater aquifer stress for simulating drawdown. During that test, PW-4-85 was pumped at 40 gpm and PW-4-118 was pumped at 50 gpm. The model with the high hydraulic conductivity zone throughout the deep alluvium and the shallow alluvium hydraulic conductivity set at 15 ft/d, as described above, was used in the analysis.

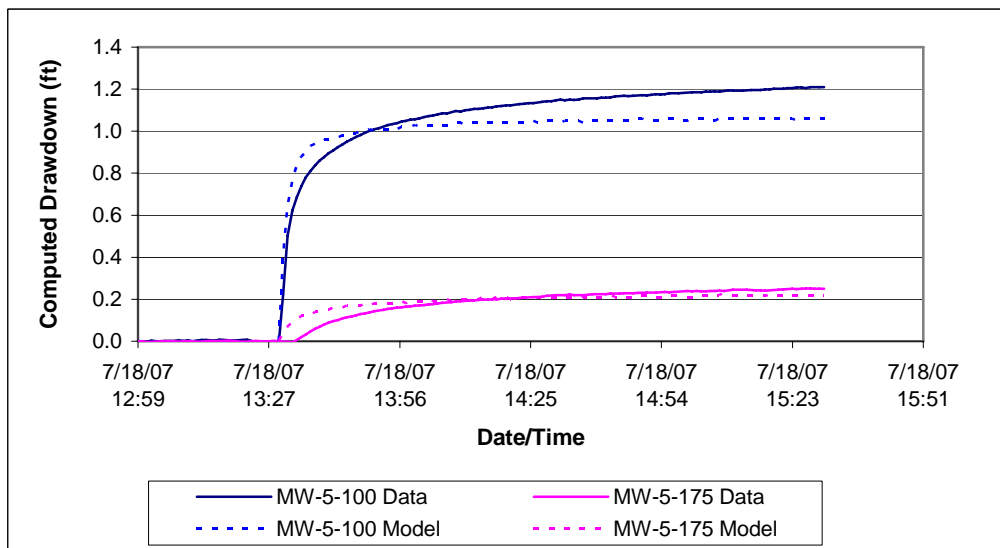
The model was used to simulate a four hour pumping period first without pumping and then with pumping. Drawdown was computed by subtracting the water levels in the pumping simulation from the water levels in the non-pumping simulations. This method keeps all boundary conditions the same for each case so that the only stress affecting drawdown is the pumping. Results of the simulation are presented on the following graph.



The computed drawdown shows a similar pattern to the drawdown in the PW-4-118 step test with substantially greater drawdown at MW-20-120 and MW-5-100 than at MW-5-175. The actual water levels at MW-5-100 and MW-5-175 during the combined PW-4 pump test are shown in the following figure.



Water levels prior to pumping can be extrapolated and used to compute drawdown during pumping. A comparison between drawdown computed from the data and drawdown computed from model results is shown in the following figure.



Drawdown computed from data and from model results show a very good match. The slightly higher drawdown computed from the data is partially explained by the trend in the data before pumping begins as the well data diverges slightly from the trend in the river stage.

Conclusion

Several additional lines of analysis are presented here that support the conceptual site model and groundwater flow model for the Gasco site.

- The analysis of grain size data indicates distinct hydraulic conductivity values for the shallow and deep alluvium.
- The hydraulic conductivity value originally used in the groundwater flow model for the shallow alluvium of 10 ft/d is consistent with the grain size analysis. However, using a higher hydraulic of 15 ft gives a higher groundwater flow rate through the site and is more consistent with estimated groundwater flow rates based on seepage meter analysis and analysis of the U.S.G.S. Portland Basin model.
- The hydraulic conductivity value of 300 ft/d used in the groundwater flow model for the deep alluvium is conservatively higher than the grain size analysis.
- Seepage rate analysis indicates that groundwater flow to the Willamette River is on the order of 225 to 253 gpm.
- Model changes to the hydraulic conductivity of the shallow alluvium and the distribution of hydraulic conductivity between the shallow and deep alluvium result in upland boundary flow that is consistent with the U.S.G.S. Portland Basin model.
- Higher boundary flows can be achieved by increasing the hydraulic conductivity of the shallow alluvium, but values quickly become out of range of the data. A hydraulic conductivity value of 15 ft/day for the shallow alluvium is not inconsistent with the data while providing a better match to estimates of groundwater flow rates from seepage meter analysis and previous modeling by the U.S.G.S. and was incorporated into the model.
- The groundwater flow model was able to simulate the PW-4 pump test and show about 0.2 ft drawdown at MW-5-175 as observed during the PW-4-118 step test and PW-4-85 and PW-4-118 combined pump test when PW-4-118 was pumped at 50 gpm.
- Considering the findings of the PW-4 pumping test, the MODFLOW model with the change described above, and the offshore seepage analysis, it is reasonable to use 250 gpm as the design basis flow rate for the shoreline extraction well system. The groundwater extraction and treatment system will be designed to handle a flow rate higher than 250 gpm to provide a factor of safety and potentially allow for treatment of water from other upland source control measures. The amount of incremental flow increase above 250 gpm will be determined in conjunction with DEQ during design of the system.

APPENDIX B1
NW NATURAL GASCO SITE:
SOURCE CONTROL EXTRACTION
SYSTEM STARTUP TEST AND
SOURCE CONTROL SCHEDULE
(POWERPOINT PRESENTATION)



NW Natural GASCO Site: Source Control Extraction System Startup Test and Source Control Schedule

Presented to Oregon DEQ and EPA on May 20, 2013

Meeting Objectives

- Discuss HC&C System Testing Plan
 - Objectives
 - Schedule
 - Data Collection
 - Data Analysis
 - Model Plans
 - Results
- Source control activities schedule
 - Document deliveries and agency review

Objectives of Source Control System Startup Testing

- Assess hydraulic capture at different delta H values
- Provide data set for calibrating source control groundwater model
- Provide the inputs needed for the Operations and Performance Monitoring and Design Report
 - Provide metrics assessed for determining hydraulic capture
 - Assess optimal parameters for operation
 - Assess need for contingencies

Preliminary Schedule for Testing Activities

- Test HC&C System from September through December 2013
 - Vary delta H values at 1-2 month intervals
 - Analyze data and select an appropriate delta H for longer-term testing
- Longer-term testing will extend from January through July 2014

Plan will Discuss Questions to be Answered during Full System Testing

- Capture will be verified as the following uncertainties are addressed
 - Water level measurements
 - River stage fluctuations
 - Monitoring well locations and screening intervals
- The effects of pumping on DNAPL
 - Thickness
 - Recovery rates
 - Gradients

Plan will Address What Data Will be Collected to Answer Questions

- Groundwater level measurements
 - Well transducers hard-wired to the PLC
 - Well transducers requiring manual data download
- River stage
- DNAPL thickness measurements
- Others?

Plan will Address How the Data will be Analyzed to Answer Questions

- Potentiometric surface maps at each delta H, and over seasons during longer-term testing
 - Fill WBZ
 - Upper Alluvium WBZ
 - Lower Alluvium WBZ
- Vertical cross-sections at select locations showing vertical gradients for each delta H, and over seasons during longer-term testing
- Changes in DNAPL thickness and recovery rates

How will Data be Used to Update GW Model?

- Model will be calibrated to startup test data for one or more delta H sets
- Model will be validated with another delta H set
 - Will provide an estimate of model's capability to simulate long-term system changes under different pumping rates and river conditions
- Particle tracking simulations will be conducted using the model to supplement assessment of capture
 - Below aquitard
 - In the Fill WBZ

Results to be Provided in Plan

- Will use both data analysis and model simulations to determine
 - Operational parameters
 - Well pumping rates
 - Vertical and horizontal gradients to be maintained
 - The need for additional extraction wells
 - The need for adding new monitoring wells and decommissioning redundant/unrepresentative monitoring wells
- Results of particle tracking and DNAPL data will be used to
 - Assess long-term DNAPL monitoring strategy
 - Select TarGOST monitoring areas

Schedule

- Discussion based on draft Excel table

APPENDIX B2
DEQ APRIL 23, 2013 EMAIL

Subject: RE: Gasco Groundwater Source Control Model Update and Uncertainty Memos

-----Original Message-----

From: BAYUK Dana [mailto:BAYUK.Dana@deq.state.or.us]

Sent: Tuesday, April 23, 2013 3:26 PM

To: John Edwards

Cc: Bob Wyatt; Patty Dost; Ben Hung; Pradeep Mugunthan; John Renda; Michael Riley; Carl Stivers; Rana Wilson; Neville, Chris; Burr, Myron; James Peale; Alan Gladstone; Sean Sheldrake; Lance Peterson (petersonle@cdmsmith.com); Scott Coffey <coffeyse@cdmsmith.com>; GAINER Tom; LARSEN Henning

Subject: RE: Gasco Groundwater Source Control Model Update and Uncertainty Memos

Good afternoon John.

DEQ reviewed the "NW Natural Gasco Site – Uncertainty Evaluation for Control Wells of the Hydraulic Control and Containment System" dated February 15, 2013 (Uncertainty Memo). Anchor QEA, LLC (Anchor) prepared the document on behalf of NW Natural.

The Uncertainty Memo responds to a request made by DEQ for NW Natural to identify sources of uncertainty associated with collecting and using the water level data during the initial testing phase of the Alluvium water-bearing zone (WBZ) hydraulic control and containment (HC&C) system. At Anchor's request, DEQ submitted a preliminary list of potential sources of data uncertainty in an e-mail dated August 7, 2012.

DEQ requested the information because not identifying sources of uncertainty and not having an approach for addressing them during the initial testing phase could complicate developing and selecting acceptable HC&C system operational parameters and performance criteria. Consequently, DEQ believes identifying sources of uncertainty and developing approaches for evaluating them will focus data collection objectives during the initial testing phase on issues relevant to long-term HC&C system operations.

DEQ's comments on the Uncertainty Memo are provided immediately below. EPA also reviewed the document and their comments are attached. Some of the DEQ and EPA comments were discussed during monthly meetings on March 18 and April 15, 2013.

DEQ is not requesting the Uncertainty Memo to be revised and resubmitted. DEQ requests instead that NW Natural conduct an evaluation of the data needs for the initial HC&C system testing phase, list out and prioritize those needs, and develop data collection objectives to address each one during testing. EPA's and DEQ's comments on the Uncertainty Memo represent a starting point for this process.

UNCERTAINTY MEMO COMMENTS

As indicated above, DEQ provided NW Natural a list of seven potential sources of uncertainty associated with water level data in early August 2012. DEQ understands from the Uncertainty Memo that NW Natural considers the list to be complete (i.e., NW Natural did not identify other sources of uncertainty). DEQ further understands that NW Natural believes the principal potential sources of uncertainty in the list are related to water level measurement error, including error associated with site surveys, transducers and transducer drift, and hand measurements made using electronic depth probes. Based on literature information, NW Natural indicates the range of uncertainty associated with each source of measurement error is 0.01-feet to 0.02-feet.

Other sources of potential water level data uncertainty identified by DEQ and referenced in the Uncertainty Memo include, seasonal river stage fluctuations, daily tidal changes, and the location and depth of monitoring wells or piezometers relative to control wells and extraction wells. Although, each of these potential sources of uncertainty involve water level fluctuations on the order of feet, the Uncertainty Memo indicates they are not sources of uncertainty either because: 1) the April 2011 variable-rate pumping tests conducted in shoreline Segment 2 indicate the HC&C system control wells can track fluctuating water levels resulting from river stage and tidal changes; or 2) adjustments can be made to the MODFLOW groundwater model to account for the location and depth of installations.

The last source of uncertainty in DEQ's August 2012 list involves the capacity of the MODFLOW model to predict small differences in water levels during HC&C system operation. NW Natural indicates this source of uncertainty will be determined during calibration of the transient MODFLOW model currently under development.

In general, DEQ considers the Uncertainty Memo to be incomplete. Although NW Natural provides estimates of the errors associated with measuring water levels and tidal fluctuations, the Uncertainty Memo does not estimate the magnitude of potential error associated with other sources of data uncertainty or discuss uncertainty in the context of the initial testing phase. The information provided in the Uncertainty Memo is insufficient to support NW Natural's recommendations to disregard certain sources of uncertainty (river stage and tidal fluctuations; installation location relative to control/extraction wells) or assess them after the initial phase of testing is complete (MODFLOW model and small differences in water levels). DEQ further understands that NW Natural intends to rely on the groundwater MODFLOW model for analyzing water level data and determining the extent of groundwater containment achieved by the HC&C system.

DEQ believes the sources of data uncertainty identified in our 8/7/12 e-mail warrant evaluation during the initial testing phase. In other words, the initial testing phase should provide water level data to evaluate NW Natural's recommendations about the significance of potential sources of uncertainty on HC&C system operations and performance. As indicated in our 8/7/12 e-mail, DEQ considers this work to be necessary for the initial operations/testing phase to be successful.

For clarification, DEQ accepts NW Natural's conclusions regarding the error associated with measuring water levels. That said, although NW Natural provides estimates of the measurement errors, the Uncertainty Memo does not indicate how the errors will be accounted for in the initial phase of HC&C testing. To accurately quantify uncertainty during testing (and long-term operations) it is necessary to "propagate" the errors associated with individual measurements through the calculations to obtain a total error. For example, the delta H values should be increased by the total error associated with location surveys and transducers readings and instrument drift. The total error associated with gradient calculations can be considered a minimum factor of safety in these cases.

DEQ requests NW Natural to further evaluate each of the sources of uncertainty during the initial phase of testing by identifying data needs for the initial testing phase, and developing corresponding data collection objectives that demonstrate NW Natural's assertions and support post-testing phase evaluations, including calibration of the transient MODFLOW model.

INITIAL TESTING PHASE PLANNING

The initial phase of testing is intended to evaluate the HC&C system prior to full-time full-scale start-up. DEQ considers the initial testing phase to be a key step in the overall process of designing, constructing, and operating the HC&C system. As indicated in DEQ's August 9, 2012 letter commenting on the Construction Design Report, numerous important data needs for the initial phase testing data have already been identified, including but not limited to:

- Developing and selecting operational parameters (e.g., delta H values, limits on extraction well pumping rates) and performance criteria (e.g., limits on horizontal and vertical gradients) for operation and performance monitoring of the HC&C system (see General Comment - Groundwater SCMs Remedial Action Objectives);
- Evaluating additional extraction wells (i.e., PW-9U and PW-10U) in Segment 2 (see Specific Comment - Category 1, Comment 19, Section 3.2.2.2.1, 2nd paragraph page 30 [also Category 2, Comment 11]);

- Supporting a full review of contingency measures for the HC&C system (see Specific Comment - Category 1, Comment 19, Section 3.2.2.2.1, 2nd paragraph page 30 (also Category 2, Comment 11);
- Using data as a line of evidence together with updated cross-sections depicting evidence of DNAPL and estimates of DNAPL transport rates, for finalizing the location of Targost Monitoring Areas (see Specific Comment - Category 1, Comment 21, Section 3.2.2.5.3, Targost Sampling); and
- Developing baseline DNAPL occurrence information and establishing an initial set of conditions for comparison with future observations and monitoring data (e.g., appearance of sheen) so informed decisions are made regarding DNAPL movement (see Related Comment - Category 3, Comment 4).

In addition to the items list above, the initial phase of testing will provide data for calibrating the transient MODFLOW model.

DEQ also notes that based on previous work NW Natural has presented numerous interpretations and opinions about the anticipated response of the Alluvium WBZ to pumping and the performance of the HC&C system. As discussed during the March and April monthly status meetings, DEQ considers the initial phase of testing to be a unique, and possibly final opportunity to evaluate NW Natural's interpretations/opinions, many of which are relevant to the design objectives and full-scale operation of the HC&C system. DEQ has put together an initial list of example data needs to serve as a starting point for identifying data collection objectives for the initial testing phase:

- Demonstrate the design objective of the upper Alluvium WBZ extraction wells in the portion of Segment 1 where DNAPL occurs (i.e., establish horizontal and vertical gradients to prevent exacerbation of DNAPL occurrence), including the sensitivity of gradients to changes in the pumping rates within and outside this group of extraction wells;
- Further evaluate interpretations from the Segment 2 tests regarding the degree of hydraulic connection between control wells and extraction wells and installations located at various locations and depths in the Alluvium WBZ, including additional details regarding the criteria for identifying installations exhibiting low or high tidal efficiency and how this information will be used to demonstrate HC&C system effectiveness;
- Demonstrate HC&C system effectiveness at monitoring wells and piezometers located at various depths in the Alluvium WBZ relative to control wells and extraction wells during periods of river stage, tidal, and barometric pressure changes;
- Use of the "Serfes" method to calculate time-averaged water levels at selected monitoring wells and piezometers for purposes of demonstrating HC&C system performance; and
- Further assess the influence of the HC&C system on the Fill WBZ.

The importance of conducting a well-planned thorough initial testing phase has increased due to NW Natural's recent proposal to continue operating the HC&C system after initial testing is conducted. NW Natural's proposal represents a significant change in the established implementation process laid-out in the Construction Design Report and agreed-to by DEQ. For DEQ to consider the proposal NW Natural should develop a rigorous plan for planning and conducting the initial phase of testing, including identification of clear objectives for the data collection and use.

NEXT STEPS

The HC&C system is designed to achieve the removal action objectives (RAOs) of: 1) preventing contaminated groundwater in the Alluvium WBZ from migrating from the uplands to the Willamette River along shoreline segments 1 and 2; and 2) minimizing DNAPL mobilization resulting from operating the system along the portion of Segment 1 where DNAPL occurs. The initial testing phase should provide: 1) the operational information necessary for the HC&C system to meet these RAOs; and 2) the basis for a performance monitoring program for demonstrating the effectiveness the HC&C system over time.

The information currently available is not sufficient for DEQ to approve the initial phase of HC&C system testing, especially given NW Natural's proposal to continue HC&C system operations after testing is conducted. Before the initial phase of testing can proceed, DEQ requests that NW Natural identify the data needs for the initial phase of testing and the data collection objectives for addressing those data needs. Furthermore, DEQ requests that the approach specify where and how each data collection objective will be addressed during the initial phase of testing.

DEQ recommends arranging a conference call or meeting late next week or early the following week to discuss EPA's and DEQ's comments and planning for the initial phase of HC&C system testing. I will check the availability of the EPA and DEQ team members and send our proposed dates and times later this week.

Please contact me with questions regarding this available.

Mr. Dana Bayuk, Project Manager
Cleanup & Portland Harbor Section
Oregon Department of Environmental Quality
2020 SW 4th Avenue, Suite 400
Portland, OR 97201
E-mail: bayuk.dana@deq.state.or.us
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FAX: 503-229-6899

Please visit our website at <http://www.oregon.gov/DEQ/>

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Footnote. Anchor QEA, LLC, 2012, "Revised Groundwater Source Control Construction Design Report, NW Natural Gasco Site," January (received January 31, 2012), a report prepared on behalf of NW Natural.

From: John Edwards [mailto:jedwards@anchorage.com]
Sent: Friday, February 15, 2013 1:58 PM
To: BAYUK Dana
Cc: Carl Stivers; Michael Riley; John Renda; Ben Hung; Neville, Chris; Rana Wilson; Bob Wyatt; Patty Dost; James Peale; Burr, Myron; Pradeep Mugunthan; Sean Sheldrake; Lance Peterson (PetersonLE@cdm.com); Coffey, Scott; John Edwards
Subject: RE: Gasco Groundwater Source Control Model Update and Uncertainty Memos

Hi Dana. The Gasco groundwater source control uncertainty evaluation memo is attached for DEQ review. The model update memo will be sent in a follow-up email. This is a fairly large pdf file, so please confirm receipt. We can place these memos on an ftp site if needed.

John
John E. Edwards, RG, CEG
ANCHOR QEA, LLC

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APPENDIX B3
DEQ MAY 15, 2013 EMAIL

Subject: RE: NW Natural, HC&C System Initial Testing Phase Work Plan

From: BAYUK Dana [<mailto:BAYUK.Dana@deq.state.or.us>]

Sent: Wednesday, May 15, 2013 5:13 PM

To: John Edwards; Ben Hung

Cc: Pradeep Mugunthan; Michael Riley; James Peale; Sean Sheldrake; 'Peterson, Lance'; Scott Coffey <coffeyse@cdmsmith.com>; GAINER Tom; LARSEN Henning

Subject: NW Natural, HC&C System Initial Testing Phase Work Plan

John/Ben.

On May 8, 2013, Anchor, Siltronic, EPA, and DEQ met to discuss DEQ/EPA comments on the Uncertainty Memo and the plan and the schedule for conducting the initial testing phase of the hydraulic control and containment (HC&C) system. Anchor submitted the Uncertainty Memo via e-mail on February 15th in response to a request made by DEQ for NW Natural to identify sources of uncertainty associated with collecting and using the water level data during the initial testing phase of the Alluvium water-bearing zone (WBZ) HC&C system. On April 23rd, DEQ e-mailed our comments on the Uncertainty Memo. DEQ's April 23rd e-mail included EPA's comments as an attachment.

In addition to providing comments on the Uncertainty Memo, DEQ's April 23rd e-mail discusses the need for developing a plan for conducting the initial phase of HC&C system testing. The e-mail also provides a preliminary list of data needs for HC&C system testing. Most of the May 8th meeting was spent discussing data needs, data collection objectives, and preparing a plan for the initial testing phase. Based on the meeting DEQ understands that:

- The current projected timeframe for beginning the initial phase of HC&C system testing is mid-August or mid-September.
- NW Natural desires to transition directly from the initial testing phase into full-scale full-time operation;
- Anchor is proposing to extend the testing phase to more fully evaluate system operations and performance for longer periods of time under changing conditions e.g., river stage fluctuations); and
- Anchor's proposal would involve operating the system for up to two months using the same delta H value, and based on the data collected, making decisions regarding changing testing parameters.

DEQ informed Anchor that both NW Natural's approach of going from the initial testing phase to full-time operations and Anchor's proposal for the initial testing phase were acceptable in concept. DEQ clarified that for us to consider NW Natural's approach and/or Anchor's proposal, a work plan should be prepared for conducting the initial phase of HC&C system testing.

Anchor and DEQ agreed during the meeting that prior to initiating the initial phase of testing, NW Natural will submit for DEQ's review and approval a plan for conducting HC&C system testing that includes, but is not limited to:

- A list of data needs for the initial testing phase, organized according to priority; and
- A corresponding list of the data collection objectives for addressing data needs, including specifying where and how during the initial phase of testing each data collection objective will be addressed.

Anchor and DEQ agreed the draft list of data needs for the initial testing phase will be submitted by May 31st. Regarding data needs, EPA's and DEQ's comments on the Uncertainty Memo provide a starting point for developing the list.

Please feel free to contact me with question regarding this e-mail, or if your understanding of the May 8th discussions is not consistent with DEQ's.

Mr. Dana Bayuk, Project Manager
Cleanup & Portland Harbor Section
Oregon Department of Environmental Quality
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APPENDIX B4
ANCHOR QEA OCTOBER 23, 2013
EMAIL

Chris Broderick

Subject: RE: DEQ Question on Gasco Treatment System Waste Stream Sampling

From: John Edwards
Sent: Friday, November 01, 2013 12:23 PM
To: Rana Wilson
Cc: John Edwards; John Renda
Subject: FW: DEQ Question on Gasco Treatment System Waste Stream Sampling

Rana, see below for the email referenced as B4 in the TOC

thanks

From: John Edwards
Sent: Wednesday, October 23, 2013 8:59 PM
To: Dana Bayuk
Cc: Ben Hung; Kirsten White; Carl Stivers; Tim Stone; Bob Wyatt; Patty Dost; Sarah Riddle; Myron Burr (Myron.Burr@siltronic.com); Alan Gladstone (agladstone@davisrothwell.com); James Peale (jpeale@maulfoster.com); 'Kerry Gallagher'; Sean Sheldrake; Lance Peterson (peteronle@cdmsmith.com); Scott Coffey (<coffeyse@cdmsmith.com>); GAINER Tom; JOHNSON Keith; LARSEN Henning; John Renda; Mike Crystal; Terry Driscoll; John Edwards
Subject: DEQ Question on Gasco Treatment System Waste Stream Sampling

Hi Dana. During our Monday team call you asked if NW Natural plans to follow the treatment system waste stream monitoring program during the upcoming source control testing. Table 2 in the May 2012 Response to Comments (Sevenson Environmental Services to DEQ) contains the elements of the monitoring program. That program will be carried out during the source control testing, with the following modifications to Table 2. The table is reproduced below.

1. We will be taking more frequent samples of the Siltronic and NW Natural influent (weekly instead of the monthly shown)
2. The influent samples for both NW Natural and Siltronic will be grab samples not composite samples.

Let us know if you have further questions.

John

John E. Edwards, RG, CEG

ANCHOR QEA, LLC

*Please note new address and phone number

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Table 2: Summary of Maximum Day Waste Streams for NW Natural Source Control Treatment Plant

Waste Stream	Maximum Day Flow, Gals/Day	Regulatory Status	Basis for Determination	Proposed Sampling Program
LIQUIDS				
<i>Siltronic Influent</i>	<i>190,339</i>	<i>May contain F002</i>	<i>Sample Data</i>	<i>Monthly composite</i>
<i>Siltronic Oil-Water Separator Effluent</i>	<i>190,339</i>	<i>May contain F002</i>	<i>Sample Data</i>	<i>As necessary</i>
<i>Siltronic Air Stripper Influent</i>	<i>190,339</i>	<i>May contain F002</i>	<i>Sample Data</i>	<i>As necessary</i>
<i>Siltronic Air Stripper Effluent</i>	<i>190,339</i>	<i>Likely will not contain F002</i>	<i>Sample Data</i>	<i>Weekly composite</i>
<i>Siltronic Blower Exhaust Air</i>	<i>Negligible</i>	<i>Will comply with ODEQ Air Quality Regulations</i>	<i>--</i>	<i>Monthly</i>
<i>Siltronic Vapor Carbon Exhaust</i>	<i>Negligible</i>	<i>Will comply with ODEQ Air Quality Regulations</i>	<i>--</i>	<i>Monthly</i>
<i>NW Natural Influent</i>	<i>752,281</i>	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>Monthly composite</i>
<i>NW Natural Oil-Water Separator Effluent</i>	<i>752,281</i>	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>NW Natural Air Stripper Influent</i>	<i>752,281</i>	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>NW Natural Air Stripper Effluent</i>	<i>752,281</i>	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>NW Natural Blower Exhaust Air</i>	<i>Negligible</i>	<i>Will comply with ODEQ Air Quality Regulations</i>	<i>--</i>	<i>Monthly</i>
<i>NW Natural Vapor Carbon</i>	<i>Negligible</i>	<i>Will comply with ODEQ</i>	<i>--</i>	<i>Monthly</i>

<i>Exhaust</i>		<i>Air Quality Regulations</i>		
<i>Combined Flow to Settling Basins</i>	798,056	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Settling Basin Effluent</i>	976,976	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Cyanide Reactor Effluent</i>	977,002	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Primary Bag Filter Effluent</i>	977,002	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>GAC Vessel Effluent</i>	977,002	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Secondary Bag Filter Effluent</i>	977,002	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Final Effluent to Willamette River</i>	946,459	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As required by permit</i>
<i>RECYCLE FLOWS</i>				
<i>Spent GAC Backwash</i>	28,260	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Gravity Thickener Overflow</i>	9,106	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>
<i>Filter Press Filtrate</i>	8,062	<i>Not hazardous waste</i>	<i>40 C.F.R. 261.24(a)</i>	<i>As necessary</i>

<i>SOLIDS</i>				
<i>Siltronic Air Stripper Vapor Carbon</i>	<i>Negligible</i>	<i>May be F002 waste</i>	<i>Sample Data</i>	<i>When disposed</i>
<i>NW Natural Air Stripper Vapor Carbon</i>	<i>Negligible</i>	<i>Solid waste</i>	<i>Sample Data</i>	<i>When disposed</i>
<i>Combined Treatment Plant Carbon</i>	87	<i>Solid waste</i>	<i>Sample Data</i>	<i>When disposed</i>
<i>Siltronic Oil Sump</i>	<i>Unknown</i>	<i>May be F002 waste</i>	<i>Sample Data</i>	<i>When disposed</i>
<i>NW Natural Oil Sumps</i>	<i>Unknown</i>	<i>Solid waste</i>	<i>Sample Data</i>	<i>When disposed</i>

<i>Settling Basin Sludge</i>	<i>17,193</i>	<i>Solid waste</i>	<i>Sample Data</i>	<i>As necessary</i>
<i>Gravity Thickener Underflow</i>	<i>8,087</i>	<i>Solid waste</i>	<i>Sample Data</i>	<i>As necessary</i>
<i>Filter Cake</i>	<i>25</i>	<i>Solid waste</i>	<i>Sample Data</i>	<i>When disposed</i>

APPENDIX B5

DEQ OCTOBER 23, 2013 EMAIL

Chris Broderick

Subject: RE: October 8 and 15, 2013 Telecon notes

From: BAYUK Dana [<mailto:BAYUK.Dana@deq.state.or.us>]

Sent: Wednesday, October 23, 2013 6:31 PM

To: John Renda

Cc: John Edwards; Ben Hung; Kirsten White; Carl Stivers; Tim Stone; Bob Wyatt; Patty Dost; Sarah Riddle; Myron Burr (Myron.Burr@siltronic.com); Alan Gladstone (agladstone@davisrothwell.com); James Peale (jpeale@maulfoster.com); 'Kerry Gallagher'; Sean Sheldrake; Lance Peterson (peteronle@cdmsmith.com); Scott Coffey (coffeyse@cdmsmith.com); GAINER Tom; JOHNSON Keith; LARSEN Henning

Subject: RE: October 8 and 15, 2013 Telecon notes

Good afternoon John.

I've read your e-mail summarizing our telephone discussions on October 8th and October 15th (see below). DEQ concurs with Anchor QEA's understanding of the call discussions regarding the DNAPL removal well at PW-14U, relocating the baseline TarGOST® boring at PW-6U, and the future depth of TarGOST® logging at PW-2L.

As far as selecting installations for more frequent collection of water level data during HC&C system testing, DEQ's review of alternatives to the five installations not currently instrumented is ongoing. DEQ anticipates completing our review next week.

DEQ has clarifying comments regarding the DNAPL removal wells to be constructed near PW-6U and PW-11U that are provided below.

PW-6U - DEQ continues to consider it a priority to construct installations at the Gasco and Siltronic sites so as not to cross-connect the Fill WBZ and the Alluvium WBZ. Consequently, DEQ acknowledges and appreciates the details provided in your e-mail regarding the depths to the contact between the Fill WBZ and Alluvium WBZ, and NW Natural's proposal to construct the installation using a screen 12-feet long. For the reasons cited in your e-mail, DEQ agrees with using a screen 12-feet in length with the top of the sand pack placed below the Fill WBZ/Alluvium WBZ contact observed at approximately 33-feet below ground surface (bgs).

PW-11U - Given the information for the DNAPL removal well near PW-6U, DEQ recommends using a screen 12-feet in length for both scenarios described in your e-mail (i.e., DNAPL funnel keyed into silt at either 34-feet or approximately 38-feet bgs) with the top of the sand pack placed below Fill WBZ/Alluvium WBZ contact observed at approximately 20-feet bgs.

Based on your 10/21 e-mail and this e-mail DEQ understands we have a path forward for constructing the three DNAPL removal wells adjacent to PW-6U, PW-11, and PW-14. DEQ further understands the next step is to identify locations for drilling and installing the wells in the field. For this purpose we've tentatively scheduled a site visit for either next Wednesday (10/30) or Friday (11/1). The location of the TarGOST® boring for PW-6U will be selected during the site visit as well.

John, I appreciate you summarizing our telephone conversations. Please contact me if you have questions regarding this e-mail, or if I haven't responded to all of the items included in your e-mail.

Hope you have a good evening.

Dana

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From: John Renda [<mailto:jrenda@anchoragea.com>]

Sent: Monday, October 21, 2013 11:15 AM

To: BAYUK Dana

Cc: John Edwards; Ben Hung; Kirsten White; Carl Stivers; Tim Stone; Bob Wyatt; Patty Dost; Sarah Riddle; Sean Sheldrake; Lance Peterson (peterstone@cdmsmith.com); Scott Coffey <coffeyse@cdmsmith.com>; GAINER Tom; LARSEN Henning

Subject: October 8 and 15, 2013 Telecon notes

Dana –

This email is to document our telephone discussions on October 8th and 15th concerning the topic below.

DNAPL Recovery Wells

DEQ requested three passive DNAPL recovery wells be installed (near PW-6U, PW-11U, and PW-14U).

DEQ agreed with a screen slot size and filter pack sand consistent with the upper alluvium extraction wells (0.020-inch slot size with 16x30 filter pack sand) as long as we are able to install the DNAPL recovery well within 20 feet of the associated upper alluvium extraction well. Additional well design details discussed are below. These wells are designed to be passive DNAPL recovery wells and they would be operated that way initially. But based on their performance, we may elect to install submersible pumps and pump groundwater from these wells in the future. We would need to have an on-site meeting with DEQ before we order well construction materials to discuss precise locations of the proposed DNAPL recovery wells and the TarGOST baseline boring at PW-6U.

- PW-6U – NAPL funnel keyed into silt at 48 feet. Screen length of 15 feet (33 to 48 feet bgs) with filter pack sand extending to approximately 30 feet bgs, noting that the fill/alluvium contact was logged at 32.6 feet bgs at PW-6U. This screen interval provides a potential downward migration pathway from the Fill WBZ to the Upper Alluvium WBZ. DEQ objected to a similar screen interval design at PW-8U and required NW Natural to decommission and replace that well. Because of that concern, we recommend installing a 12-foot screen (36 to 48 feet bgs) with filter pack sand extending to approximately 33 feet bgs.
- PW-11U – NAPL funnel keyed into silt at 34 feet or keyed in the silt layers at 37.7 to 39.7. Screen length of 10 feet. Sand pack not above 19.5 bgs (fill/alluvium contact)
- PW-14U - NAPL funnel keyed into silt at 46.5 feet. Screen length of 15 feet (46.5 to 31.5). Sand pack to 30 feet.

TarGOST borings

Installing a DNAPL recovery well near PW-6U would necessitate moving the follow-up TarGOST borings at this location away from the baseline TarGOST boring. DEQ stated that the new TarGOST boring at this location would be treated as a new baseline. We need to meet at the site and agree on a suitable new location for the PW-6U TarGOST baseline before we can finalize our plans.

We discussed the depth of TarGOST borings adjacent extraction wells and DEQ requested that the TarGOST boring adjacent to PW-2U be advanced to the total depth of PW-2L (147 feet bgs). This depth was selected to avoid penetrating the deep aquitard at this location.

Transducer Frequency

In a September 11, 2013 email, DEQ proposed a list of 24 wells to have the transducer data collection interval decreased to 1-minute or less. In an email response to DEQ on September 16, 2013 it was pointed out that 5 of the wells are not instrumented with transducers. When last discussed on October 15, 2013, DEQ was still evaluating if the 19 remaining wells are sufficient.

John J. Renda, RG

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APPENDIX C

SAMPLING AND ANALYSIS PLAN

APPENDIX C SAMPLING AND ANALYSIS PLAN GROUNDWATER SOURCE CONTROL EXTRACTION SYSTEM TEST PLAN NW NATURAL GASCO SITE

Prepared for

NW Natural

Prepared by

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August 2013

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LIST OF ACRONYMS AND ABBREVIATIONS

±	plus or minus
%R	percent recovery
Anchor QEA	Anchor QEA, LLC
ASTM	ASTM International
CCV	continuing calibration verifications
CFR	Code of Federal Regulations
COC	chain-of-custody
DEQ	Oregon Department of Environmental Quality
DO	dissolved oxygen
DQO	data quality objective
FC	field coordinator
GC	gas chromatography
HAZWOPER	Hazardous Waste Operations and Emergency Response
L/min	liter per minute
MDL	method detection limit
MRL	method reporting limit
MS	matrix spike
MSD	matrix spike duplicate
NIST	National Institute of Standards and Technology
OSHA	Occupational Safety and Health Administration
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RL	reporting limit
RPD	relative percent difference
SAP	Sampling and Analysis Plan
Site	NW Natural Gasco Site

SOP	standard operating procedure
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compounds

1 INTRODUCTION

This Sampling and Analysis Plan (SAP) has been prepared as Appendix C to the *Groundwater Source Control Extraction System Test Plan*. This plan was adapted from the SAP prepared as Appendix O of the *Revised Groundwater Source Control Construction Design Report* for the NW Natural Gasco Site (Site) in Portland, Oregon. This SAP covers monitoring of groundwater hydrology and chemistry in select monitoring wells during testing of the recently constructed groundwater source control hydraulic control and containment system for Segments 1 and 2 at the Site.

2 HYDROLOGY MONITORING

2.1 Manual Water Level Monitoring

Following the procedures described herein, manual water level measurements will be made in selected monitoring wells, pumping wells, observation wells, and piezometers before and after the water level transducers are in place. The manual measurements will be used as reference points for the data generated by the transducer equipment. Measurements will be taken with an electronic water level indicator. Levels will be measured to the nearest 0.01 foot from a surveyed notch or mark at the top of the polyvinyl chloride (PVC) casing or other reference point. Measurements will be recorded immediately on a water level record sheet with the date, time (on a 24-hour clock), reference point, and initials of the person who made the measurements. The manual measurements will be used to calibrate the pressure transducers and monitor for “drift” of the readings. The water level indicator will be decontaminated in between wells, as specified in the following subsections.

2.2 Transducer Water Level Monitoring

Accurate, time-coincident measurements will be used to evaluate the performance of the extraction well pumping system. Pressure transducers have been installed in selected wells and in the Willamette River to collect time-coincident water level data for several depth intervals. For long-term monitoring, the data download frequency will be a minimum of twice per month to recalibrate the transducers and make sure that excessive drift is not occurring. However, data download frequency could be more frequent for short-term tests that require downloads at the beginning and end of the tests. Manual water level measurements will also be made when the transducer checks are made. If the manual measurement is off by more than 0.1 foot from the transducer reading, the transducer will be corrected.

2.2.1 Pressure Transducer Installation

Pressure transducers (15 pounds per square inch, in situ mini-TROLL professional, in situ level TROLL, or similar) have been installed at the selected locations. The pressure transducers were installed using cables that extend from the surface to the instrument that is submerged in the well or river water. The cables allow in situ calibration of depth-to-water measurements from the surface. The full-length cables also allow for venting to the atmosphere, eliminating the need for barometric data correction.

The following procedure will be used to install the transducers:

1. Each instrument will be connected to a communication/vent cable of the appropriate length.
2. The instrument and cable will be decontaminated before and after installation using the subsequent procedures.
3. The instrument will be calibrated to zero in ambient air conditions.
4. The instrument and cable will be slowly fed down into the well to a depth that will ensure submersion throughout the monitoring period.
5. The instrument cable will be securely attached to the well casing.
6. The instrument and cable will cause the displacement of water in the well casing; therefore, the water level in the well will be allowed to equilibrate for 30 to 60 minutes before depth-to-water reference measurements are entered into the instrument.
7. The installer will connect to the instrument cable with a portable personal computer.
8. The installer will use an electric water level indicator to measure the depth-to-water from the monitoring point and enter the result into the instrument as a real-time reference value. The installer will repeat the measurement and record both readings for quality control (QC).
9. The installer will program the instrument to collect one measurement of temperature and depth-to-water (pressure) every 15 minutes.
10. The above-ground connector on the cable will be protected by a desiccant filter that is designed specifically for this application.

3 WATER QUALITY MONITORING

Groundwater samples will be collected from selected wells during the implementation of source control testing. Groundwater samples will be collected from extraction wells, monitoring wells, and piezometers along the shoreline of the Site. The selected wells and frequency of sampling are described in the *Groundwater Source Control Extraction System Test Plan*. The test plan also describes the target analytes, including volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons, total metals, and total, available, and free cyanide.

3.1 Groundwater Sample Collection Procedures

Prior to groundwater sample collection, depth-to-water readings from the top of the well casing will be measured using a water level indicator. The water level indicator will be decontaminated between wells using the procedures outlined later in this section.

The wells will then be purged using low flow (minimal drawdown) groundwater sampling procedures (USEPA 1996). Purging will be completed using a Waterra displacement pump, peristaltic pump, or dedicated submersible pump. The pump rate will be set to the lowest setting, and the pump will be turned on. Once started, turning the pump on and off should be avoided because this allows the water column in the tubing to surge back into the well, possibly mobilizing particulate material. Similarly, significant variations in flow rate should be avoided, as these actions can result in surging. The flow rate will be adjusted to ensure no more than 0.3 feet of drawdown occurs within the well. The U.S. Environmental Protection Agency (USEPA) guidance document suggests typical flow rates of less than 0.5 liters per minute (L/min) but can be as high as 1 L/min. The lowest possible sustainable flow rate should be achieved. If the water table level cannot be maintained, standard purging methods may be used, as described subsequently. Stabilization parameter measurements will be recorded on the field sampling data sheet at an appropriate time interval (every 3 to 5 minutes). Parameter measurements include time, purge volume, water level, temperature, specific conductivity, dissolved oxygen (DO), pH, oxidation reduction potential, and turbidity. Stabilization has occurred after three successive readings within plus or minus (\pm) 0.1 for pH, \pm 3 percent for conductivity, \pm 10 millivolt for redox potential, and \pm 10 percent for turbidity and DO. Once stabilization has occurred in the selected parameters, sampling may begin. Should individual parameters not stabilize after a reasonable amount of purging (two to three casing volumes), pumping rates will be increased, and standard purging techniques will be followed. The pump will not be stopped until the sample collection is complete.

As discussed previously, if low flow sampling is not possible due to drawdown or unstable field parameters, the well will be sampled by purging of at least three well casing volumes before groundwater is collected. Purging will be accomplished with one of the following methods: peristaltic pump with dedicated polyethylene tubing, Waterra inertial pump with dedicated Waterra tubing and check-valve, a disposable polyethylene bailer, or a submersible pump. Note that dedicated tubing or piping will be installed in all wells, either for use with a peristaltic pump for shallow wells or an inertial pump or as a discharge line to a submersible pump. A bailer is only noted above as a contingent sampling device due to pump failure. After each well casing volume has been purged, water quality parameters (pH, specific conductance, temperature, turbidity, and DO) will be recorded using a calibrated water quality meter. The well will be considered adequately purged when the water quality parameters have stabilized to within ± 10 percent of the previous measurement. Care will be taken to produce low turbidity samples with a goal of turbidity below 50 Nephelometric Turbidity Units; however, this is not always possible with poorly producing wells or with wells screened in highly silty or clayey soil.

After the water quality parameters have stabilized, the sample will be collected directly from the dedicated tubing or disposable bailer into the sample container. If standard purging techniques are used, pumping rates will be reduced during sample collection. In the event that a bailer is used, a low flow, bottom emptying device will be used to fill VOC containers. The samples will then be stored on ice for shipment to an analytical laboratory.

4 EQUIPMENT CLEANING AND DECONTAMINATION PROCEDURES

Decontamination procedures are specified in this section. The objective for decontamination is to reduce the chance of cross-contaminating samples. All waters generated by cleaning and decontamination will be contained and disposed of. The water from sampling the Site wells will be treated in the on-Site treatment system. The water from sampling wells on the Siltronic site will be evaluated to select the appropriate treatment or disposal option.

4.1 Groundwater Monitoring Equipment

Groundwater sampling equipment includes items used during groundwater sampling and water level monitoring. Dedicated or single-use sampling equipment will be used for sample collection; however, equipment such as water level probes and oil/water interface probes will require decontamination. All equipment that contacts groundwater will be decontaminated before its first use and between sampling locations. Decontamination will proceed as follows:

- Distilled-water rinse
- Non-phosphatic detergent (e.g., Liquinox) and water wash
- Distilled water rinse
- Final distilled water rinse

5 QUALITY ASSURANCE PLAN

5.1 Data Quality Objectives and Criteria

The overall data quality objective (DQO) for this project is to ensure that the data collected are of known and acceptable quality, so the project objectives described in this document can be achieved. The quality of the laboratory data is assessed by precision, accuracy, representativeness, comparability, and completeness (the "PARCC" parameters). Definitions of these parameters and the applicable QC procedures are given in the subsequent sections. Applicable quantitative goals for these data quality parameters are listed or referenced in Table C-1.

5.1.1 Precision

Precision is the ability of an analytical method or instrument to reproduce its own measurement. It is a measure of the variability, or random error, in sampling, sample handling, and in laboratory analysis. ASTM International (ASTM) recognizes two levels of precision: repeatability—the random error associated with measurements made by a single test operator on identical aliquots of test material in a given laboratory, with the same apparatus, under constant operating conditions; and reproducibility—the random error associated with measurements made by different test operators, in different laboratories, using the same method but different equipment to analyze identical samples of test material.

In the laboratory, "within-batch" precision is measured using replicate sample or QC analyses and is expressed as the relative percent difference (RPD) between the measurements. The "batch-to-batch" precision is determined from the variance observed in the analysis of standard solutions or laboratory control samples from multiple analytical batches.

Field precision will be evaluated by the collection of blind field duplicates for chemistry samples at a frequency of one in ten samples. Field chemistry duplicate precision will be screened against an RPD of 50 percent for groundwater samples. However, no data will be qualified based solely on field duplicate precision.

Precision measurements can be affected by the nearness of a chemical concentration to the method detection limit (MDL), where the percent error (expressed as RPD) increases. The equation used to express precision is as follows:

$$RPD = \frac{(C_1 - C_2) \times 100\%}{(C_1 + C_2)/2}$$

Where:

RPD = relative percent difference

C₁ = larger of the two observed values

C₂ = smaller of the two observed values

5.1.2 Accuracy

Accuracy is a measure of the closeness of an individual measurement (or an average of multiple measurements) to the true or expected value. Accuracy is determined by calculating the mean value of results from ongoing analyses of laboratory-fortified blanks, standard reference materials, and standard solutions. In addition, laboratory-fortified (i.e., matrix-spiked) samples are also measured; this indicates the accuracy or bias in the actual sample matrix. Accuracy is expressed as percent recovery (%R) of the measured value relative to the true or expected value. If a measurement process produces results for which the mean is not the true or expected value, the process is said to be biased. Bias is the systematic error either inherent in a method of analysis (e.g., extraction efficiencies) or caused by an artifact of the measurement system (e.g., contamination). Analytical laboratories utilize several QC measures to eliminate analytical bias, including systematic analysis of method blanks, laboratory control samples, and independent calibration verification standards. Because bias can be positive or negative, and because several types of bias can occur simultaneously, only the net (or total) bias can be evaluated in a measurement.

Laboratory accuracy will be evaluated against quantitative matrix spike (MS) and surrogate spike recovery performance criteria provided by the laboratory. Accuracy can be expressed as a percentage of the true or reference value or as a %R in those analyses where reference materials are not available and spiked samples are analyzed. The equation used to express accuracy is as follows:

$$\%R = 100\% \times (S-U)/C_{sa}$$

Where:

%R	=	percent recovery
S	=	measured concentration in the spiked aliquot
U	=	measured concentration in the unspiked aliquot
C _{sa}	=	actual concentration of spike added

Field accuracy will be controlled by adherence to sample collection procedures outlined in the SAP.

5.1.3 *Bias*

Bias is the systematic or persistent distortion of a measurement process that causes errors in one direction. Bias assessments for environmental measurements are made using personnel, equipment, and spiking or reference materials as independent as possible from those used in the calibration of the measurement system. When possible, bias assessments should be based on analysis of spiked samples rather than reference materials, so the effect of the matrix on recovery is incorporated into the assessment. A documented spiking protocol, and consistency in following that protocol, is important to obtaining meaningful data quality estimates.

5.1.4 *Representativeness*

Representativeness expresses the degree to which data accurately and precisely represent an environmental condition. For the Site, the list of analytes has been identified to provide a comprehensive assessment of the known and potential contaminants at the Site.

5.1.5 *Comparability*

Comparability expresses the confidence with which one dataset can be evaluated in relation to another dataset. For this program, comparability of data will be established through the use of standard analytical methodologies and reporting formats, as well as the use of common traceable calibration and reference materials.

5.1.6 *Completeness*

Completeness is a measure of the amount of data that is determined to be valid in proportion to the amount of data collected. Completeness will be calculated as follows:

$$C = \frac{(\text{Number of acceptable data points}) \times 100}{(\text{Total number of data points})}$$

The DQO for completeness for all components of this project is 90 percent. Data that have been qualified as estimated because the QC criteria were not met will be considered valid for the purpose of assessing completeness. Data that have been qualified as rejected will not be considered valid for the purpose of assessing completeness.

5.1.7 *Sensitivity*

Analytical sensitivities must be consistent with or lower than the regulated criteria values to demonstrate compliance with this section. When they are achievable, target detection limits specified will be at least a factor of two less than the analyte's corresponding regulated criteria value.

The MDL is defined as the minimum concentration at which a given target analyte can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero. Laboratory practical quantitation limits or reporting limits (RLs) are defined as the lowest level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. Laboratory MDLs and RLs will be used to evaluate the method sensitivity and applicability prior to the acceptance of a method for this program.

The sample-specific MDL and RL will be reported by the laboratory and will take into account any factors relating to the sample analysis that might decrease or increase the RL (e.g., dilution factor, percent moisture, sample volume, and sparge volume). In the event that the MDL and RL are elevated for a sample due to matrix interferences and subsequent dilution or reduction in the sample aliquot, the data will be evaluated by Anchor QEA, LLC (Anchor QEA) and the laboratory to determine if an alternative course of action is required or possible. If this situation cannot be resolved readily (i.e., detection limits less than criteria are achieved), the Oregon Department of Environmental Quality (DEQ) will be contacted to discuss an acceptable resolution. The sample-specific RL will be the value provided in the project database and subsequent EQuIS deliverable.

5.1.8 *Special Training Requirements/Certifications*

The 29 Code of Federal Regulations (CFR) 1910.120 Occupational Safety and Health Administration (OSHA) regulations require training to provide employees with the knowledge and skills enabling them to perform their jobs safely and with minimum risk to their personal health. All sampling personnel will have completed the 40-hour Hazardous Waste Operations and Emergency Response (HAZWOPER) training course and 8-hour refresher courses, as necessary, to meet the OSHA regulations.

5.2 *Documentation and Records*

This project will require central project files to be maintained at Anchor QEA. Project records will be stored and maintained in a secure manner. Each project team member is responsible for filing all necessary project information or providing it to the person responsible for the filing system. Individual team members may maintain files for individual tasks but must provide such files to the central project files upon completion of each task. A project-specific index of file contents is to be kept with the project files. Hard copy documents will be kept on file at Anchor QEA or at a document storage facility throughout the duration of the project, and all electronic data will be maintained in the database at Anchor QEA.

5.2.1 *Field Records*

All documents generated during the field effort are controlled documents that become part of the project file.

5.2.1.1 *Field Forms*

Field team members will keep a daily record of significant events, observations, and measurements on field forms. Copies of typical field forms are in Attachment C-1. All field activities will be recorded on forms specific to the collection activity and will be maintained by the field coordinator (FC). Field forms will be the main source of field documentation for all field activities. The on-site field representative will record on the field log form information pertinent to the investigation program. The sampling documentation will contain information on each sample collected and will include at a minimum the following information:

- Project name
- Field personnel on site
- Facility visitors
- Weather conditions

- Field observations and any deviations from the SAP
- Maps and drawings
- Date and time sample collected
- Sampling method and description of activities
- Identification or serial numbers of instruments or equipment used
- Deviations from the SAP
- Conferences associated with field sampling activities

The field forms will be on water-resistant, durable paper for adverse field conditions. Notes will be taken in indelible, waterproof blue or black ink. Errors will be corrected by crossing out with a single line, dating, and initialing. Each form will be marked with the project name, number, and date. The field forms will be scanned into Anchor QEA's project file directory, as convenient during the sampling event or upon completion of each sampling event.

Sample collection tables will be prepared prior to each sampling program. The checklist will include proposed coordinates of each location, the sampling scheme, and whether any QC samples are to be collected.

5.2.2 Analytical and Chemistry Records

Analytical data records will be retained by the laboratory and in the Anchor QEA central project files. For all analyses, the data reporting requirements will include those items necessary to complete data validation, including copies of all raw data. The analytical laboratory will be required, where applicable, to report the following:

- **Project Narrative.** This summary, in the form of a cover letter, will discuss problems, if any, encountered during any aspect of analysis. This summary should discuss, but not be limited to, QC, sample shipment, sample storage, and analytical difficulties. Any problems encountered, actual or perceived, and their resolutions will be documented in as much detail as appropriate.
- **Chain-of-Custody (COC) Records.** Legible copies of the COC forms will be provided as part of the data package. This documentation will include the time of receipt and condition of each sample received by the laboratory. Additional internal tracking of sample custody by the laboratory will also be documented on a sample receipt form. The form must include all sample shipping container temperatures measured at the time of sample receipt.

- **Sample Results.** The data package will summarize the results for each sample analyzed. The summary will include the following information, when applicable:
 - Field sample identification code and the corresponding laboratory identification code
 - Sample matrix
 - Date of sample extraction
 - Date and time of analysis
 - Weight and volume used for analysis
 - Final dilution volumes or concentration factor for the sample
 - Identification of the instrument used for analysis
 - MDLs
 - Method reporting limits (MRLs) accounting for sample-specific factors (e.g., dilution, total solids)
 - Analytical results with reporting units identified
 - Data qualifiers and their definitions
 - A computer disk with the data in a format specified in advance by Anchor QEA
- **Quality Assurance (QA)/QC Summaries.** This section will contain the results of the laboratory QA/QC procedures. Each QA/QC sample analysis will be documented with the same information required for the sample results. No recovery or blank corrections will be made by the laboratory. The required summaries are listed subsequently; additional information may be requested.
- **Calibration Data Summary.** This summary will report the concentrations of the initial calibration and daily calibration standards, and the date and time of analysis. The response factor, percent relative standard deviation, percent difference, and retention time for each analyte will be listed, as appropriate. Results for standards to indicate instrument sensitivity will be documented.
- **Internal Standard Area Summary.** The stability of internal standard areas will be reported.
- **Method Blank Analysis.** The method blank analyses associated with each sample and the concentration of all compounds of interest identified in these blanks will be reported.
- **Surrogate Spike Recovery.** This will include all surrogate spike recovery data for organic compounds. The name and concentration of all compounds added, %Rs, and range of recoveries will be listed.

- **MS Recovery.** This will report all MS recovery data for organic and metal compounds. The name and concentration of all compounds added, %Rs, and range of recoveries will be listed. The RPD for all duplicate analyses will be included.
- **Matrix Duplicate.** This will include the %R and associated RPD for all matrix duplicate analyses.
- **Laboratory Control Sample.** All laboratory control sample recovery data for organic and metal compounds will be reported. The name and concentration of all compounds added, %Rs, and range of recoveries will be listed. The RPD for all duplicate analyses will be included.
- **Relative Retention Time.** This will include a report of the relative retention time of each analyte detected in the samples for both primary and conformational analyses.
- **Original Data.** Legible copies of the original data generated by the laboratory will include the following:
 - Sample extraction, preparation, identification of extraction method used, and cleanup logs
 - Instrument specifications and analysis logs for all instruments used on days of calibration and analysis
 - Calculation worksheets for inorganic analyses
 - Reconstructed ion chromatograms for all samples, standards, blanks, calibrations, spikes, replicates, and reference materials
 - Original printouts of full scan chromatograms and quantitation reports for all gas chromatography (GC) and/or GC/MS samples, standards, blanks, calibrations, spikes, replicates, and reference materials
 - Enhanced spectra of detected compounds with associated best-match spectra for each sample

All instrument data shall be fully restorable at the laboratory from electronic backup.

Laboratories will be required to maintain all records relevant to project analyses for a minimum of 7 years. Data validation reports will be maintained in the central project files with the analytical data reports.

5.2.3 Data Reduction

Data reduction is the process by which original data (analytical measurements) are converted or reduced to a specified format or unit to facilitate analysis of the data. Data reduction requires

that all aspects of sample preparation that could affect the test result, such as sample volume analyzed or dilutions required, be taken into account in the final result. It is the laboratory analyst's responsibility to reduce the data, which are subjected to further review by the laboratory manager, the project manager, the QA/QC manager, and independent reviewers. Data reduction may be performed manually or electronically. If performed electronically, all software used must be demonstrated to be true and free from unacceptable error. The following will be included in the data report:

- Copies of complete laboratory data packages, as appendices or attachments
- Copies of applicable sections of the field log, as appendices or attachments
- Copies of validation reports and/or findings

5.3 Overview of Data Generation and Acquisition

The rationale for the sampling design and design assumptions for locating and selecting environmental samples is detailed in the *Draft Groundwater Source Control Final Design Report*. The methods and procedures for collection of field samples are also provided in the *Draft Groundwater Source Control Final Design Report*.

5.3.1 Analytical Methods

This section summarizes the target chemical analyses for the samples. All sample analyses will be conducted in accordance with DEQ-approved methods. Prior to analysis, all samples will be maintained according to the appropriate holding times and temperatures for each analysis as defined in Table C-2. Table C-1 presents the proposed analytes, the analytical methods to be used, and the targeted RLs for the chemical testing. The analytical laboratory will prepare a detailed report in accordance with this section, to be included as an appendix in the data report.

Prior to the analysis of the samples, the laboratory will calculate MDLs for each analyte of interest, where applicable. MRLs will be below the values specified in Table C-1, if technically feasible. To achieve the required detection limits, some modifications to the methods may be necessary. These modifications from the specified analytical methods will be provided by the laboratory at the time of establishing the laboratory contract, and must be approved by DEQ prior to implementation.

Chemical testing will be conducted at an accredited laboratory under the National Environmental Laboratories Accreditation Program. In completing chemical analyses for this project, the contract laboratory is expected to meet the following minimum requirements:

- Adhere to the methods outlined in this section, including methods referenced for each analytical procedure (see Table C-1).
- Deliver facsimile, hard copy, and electronic data as specified.
- Meet reporting requirements for deliverables.
- Meet turnaround times for deliverables.
- Implement QA/QC procedures, including DQOs, laboratory QC requirements, and performance evaluation testing requirements.
- Notify the project QA/QC manager of any QA/QC problems when they are identified to allow for quick resolution.
- Allow laboratory and data audits to be performed, if deemed necessary.

5.3.2 *Quality Assurance and Quality Control*

Field and laboratory activities must be conducted in such a manner that the results meet specified quality objectives and are fully defensible. Guidance for QA/QC is derived from the protocols developed for the USEPA SW-846 (1986), the USEPA Contract Laboratory Program (USEPA 2008), and the cited methods.

5.3.2.1 *Field Quality Control*

Anchor QEA personnel will identify and label samples in a consistent manner to ensure that field samples are traceable and that labels provide all information necessary for the laboratory to conduct required analyses properly. Samples will be placed in appropriate containers and preserved for shipment to the laboratory.

5.3.2.1.1 Sample Containers

Sample containers and preservatives will be provided by the laboratory. The laboratory will maintain documentation certifying the cleanliness of bottles and the purity of preservatives provided. Specific container requirements will be subject to the sample design as described in this section.

5.3.2.1.2 Sample Identification and Labels

Each sample will have an adhesive plastic or waterproof paper label affixed to the container and will be labeled at the time of collection. The following information will be recorded on the container label at the time of collection:

- Project name
- Sample identification
- Date and time of sample collection
- Preservative type (if applicable)
- Analysis to be performed

Samples will be uniquely identified with a sample identification that at a minimum specifies sample matrix, sample number, sample location, and type of sample.

5.3.2.1.3 Sample Custody and Shipping Requirements

Samples are considered to be in one's custody if they are: 1) in the custodian's possession or view; 2) in a secured location (under lock) with restricted access; or 3) in a container that is secured with an official seals such that the sample cannot be reached without breaking the seals.

COC procedures will be followed for all samples throughout the collection, handling, and analysis process. The principal document used to track possession and transfer of samples is the COC form. Each sample will be represented on a COC form the day it is collected. All data entries will be made using indelible ink pen. Corrections will be made by drawing a single line through the error, writing in the correct information, then dating and initialing the change. Blank lines or spaces on the COC form will be lined-out, dated, and initialed by the individual maintaining custody.

A COC form will accompany each cooler of samples to the analytical laboratories. Each person who has custody of the samples will sign the COC form and ensure that the samples are not left unattended unless properly secured. Copies of all COC forms will be retained in the project files.

All samples will be shipped to the analytical laboratory no later than the day after collection. Samples collected on Friday may be held until the following Monday for shipment provided

that this does not jeopardize any hold time requirements. Specific sample shipping procedures are as follows:

- Each cooler or container containing the samples for analysis will be hand-delivered by courier or shipped via overnight delivery to the appropriate analytical laboratory. In the event that Saturday delivery is required, the FC will contact the analytical laboratory before 3 p.m. on Friday to ensure that the laboratory is aware of the number of coolers shipped and the airbill tracking numbers for those coolers. Following each shipment, the FC will call the laboratory and verify that the shipment from the day before has been received and is in good condition.
- Coolant ice will be placed in the shipping containers. It will be placed in durable sealable plastic bags to limit leakage during transit.
- Individual sample containers will be packed to prevent breakage, and transported in a sealed ice chest or other suitable container.
- Glass jars will be separated in the shipping container by shock absorbent material (e.g., bubble wrap) to prevent breakage.
- The shipping containers will be clearly labeled with sufficient information (name of project, time and date container was sealed, person sealing the container, and consultant's office name and address) to enable positive identification.
- A sealed envelope containing COC forms will be enclosed in a plastic bag and taped to the inside lid of the cooler.
- A minimum of two signed and dated COC seals will be placed on adjacent sides of each cooler prior to shipping.
- Each cooler will be wrapped securely with strapping tape and will be clearly labeled with the laboratory's shipping address and the consultant's return address.
- Upon transfer of sample possession to the analytical laboratory, the persons transferring custody of the sample container will sign the COC form. Upon receipt of samples at the laboratory, the shipping container seal will be broken, and the receiver will record the condition of the samples on a sample receipt form. The temperature of each cooler will be measured upon receipt and recorded on the sample receipt form. COC forms will be used in the laboratory to track sample handling and final disposition.

5.3.2.1.4 Field Quality Assurance Sampling

Field QA procedures will consist of following procedures for acceptable practices for collecting and handling of samples. Adherence to these procedures will be complemented by periodic and routine equipment inspection.

Field QA samples will be collected along with the environmental samples. Field QA samples are useful in identifying possible problems resulting from sample collection or sample processing in the field. The collection of field QA samples includes field blanks and duplicate samples. Duplicate samples will be collected at a frequency of one duplicate sample per ten (10 percent frequency) and field blanks will be collected at a frequency of one sample per 20 (5 percent frequency). The field blank will be analyzed for the identical chemical list as the groundwater samples. In addition, a trip blank will be included in each shipping container that includes samples for volatiles analysis. The trip blank samples will be analyzed for VOCs.

Field QA samples will also include the collection of additional sample volume, to ensure that the laboratory has sufficient sample volume to run the program-required analytical QA/QC (MS/matrix spike duplicate [MSD]) samples for analysis as specified in Table C-4. Additional sample volume to meet this requirement will be collected at a frequency of one per sampling event or one in 20 samples processed, whichever is more frequent. The samples designated for MS/MSD analyses should be clearly marked on the COC.

All field QA samples will be documented on the field forms and verified by the QA/QC manager or designee.

5.3.2.2 Laboratory Quality Control

Laboratory QC procedures, where applicable, include initial and continuing instrument calibrations, standard reference materials, laboratory control samples, matrix replicates, MSs, surrogate spikes (for organic analyses), and method blanks. Table C-4 lists the frequency of analysis for laboratory QA/QC samples, and Table C-3 summarizes the DQOs of sample testing for precision, accuracy, and completeness.

Results of the QC samples from each sample group will be reviewed by the analyst immediately after a sample group has been analyzed. The QC sample results will then be evaluated to determine if control limits have been exceeded. If control limits are exceeded in the sample group, the QA/QC manager will be contacted immediately, and corrective action (e.g., method

modifications followed by reprocessing the affected samples) will be initiated prior to processing a subsequent group of samples.

5.3.2.2.1 Laboratory Instrument Calibration and Frequency

An initial calibration will be performed on each laboratory instrument to be used at the start of the project, after each major interruption to the analytical instrument, and when any ongoing calibration does not meet method control criteria. A calibration verification will be analyzed following each initial calibration and will meet method criteria prior to analysis of samples. Continuing calibration verifications (CCV) will be performed daily prior to any sample analysis to track instrument performance. The frequency of CCVs varies with method. For GC/MS methods, one will be analyzed every 12 hours. For GC, metals, and inorganic methods, one will be analyzed for every ten field samples, or daily, whichever is more frequent. If the ongoing continuing calibration is out of control, the analysis must come to a halt until the source of the control failure is eliminated or reduced to meet control specifications. All project samples analyzed while instrument calibration was out of control will be reanalyzed.

Instrument blanks or continuing calibration blanks provide information on the stability of the baseline established. Continuing calibration blanks will be analyzed immediately prior to CCV at the instrument for each type of applicable analysis.

5.3.2.2.2 Laboratory Duplicates/Replicates

Analytical duplicates provide information on the precision of the analysis and are useful in assessing potential sample heterogeneity and matrix effects. Analytical duplicates and replicates are subsamples of the original sample that are prepared and analyzed as a separate sample.

5.3.2.2.3 MS and MSDs

Analysis of MS samples provides information on the extraction efficiency of the method on the sample matrix. By performing duplicate MS analyses, information on the precision of the method is also provided for organic analyses.

5.3.2.2.4 Method Blanks

Method blanks are analyzed to assess possible laboratory contamination at all stages of sample preparation and analysis. The method blank for all analyses must be less than the MRL of any

single target analyte/compound. If a laboratory method blank exceeds this criterion for any analyte/compound, and the concentration of the analyte/compound in any of the samples is less than five times the concentration found in the blank (ten times for common contaminants), analyses must stop, and the source of contamination must be eliminated or reduced.

5.3.2.2.5 Laboratory Control Samples

Laboratory control samples are analyzed to assess possible laboratory bias at all stages of sample preparation and analysis. The laboratory control sample is a matrix-dependent spiked sample prepared at the time of sample extraction along with the preparation of sample and MSs. The laboratory control sample will provide information on the precision of the analytical process and, when analyzed in duplicate, will provide accurate information.

5.3.2.2.6 Laboratory Deliverables

Data packages will be checked for completeness immediately upon receipt from the laboratory to ensure that data and QA/QC information requested are present. Data quality will be assessed by considering the following:

- Holding times
- All compounds of interest reported
- RLs
- Surrogate spike results
- MS/MSD results
- Blank spikes
- Laboratory control samples/laboratory control sample duplicates
- Standard reference material results
- Method blanks
- Detection limits

5.3.3 ***Instrument/Equipment Testing, Inspection, and Maintenance Requirements***

This section describes procedures for testing, inspection, and maintenance of field and laboratory equipment.

5.3.3.1 *Field Instruments/Equipment*

In accordance with the QA program, Anchor QEA shall maintain an inventory of field instruments and equipment. The frequency and types of maintenance will be based on the manufacturer's recommendations and/or previous experience with the equipment.

The frequency of maintenance is dependent on the type and stability of the equipment, the methods used, the intended use of the equipment, and the recommendations of the manufacturer. Detailed information regarding the calibration and frequency of equipment calibration is provided in specific manufacturer's instruction manuals.

All maintenance records will be verified prior to each sampling event. The FC will be responsible for verifying that required maintenance has been performed prior to using the equipment in the field.

5.3.3.2 *Laboratory Instruments/Equipment*

In accordance with the QA program, the laboratory shall maintain an inventory of instruments and equipment and the frequency of maintenance will be based on the manufacturer's recommendations and/or previous experience with the equipment.

The laboratory preventative maintenance program, as detailed in their QA Plan, is organized to maintain proper instrument and equipment performance, and to prevent instrument and equipment failure during use. The program considers instrumentation, equipment, and parts that are subject to wear, deterioration, or other changes in operational characteristics, the availability of spare parts, and the frequency at which maintenance is required. Any equipment that has been overloaded, mishandled, gives suspect results, or has been determined to be defective will be taken out of service, tagged with the discrepancy noted, and stored in a designated area until the equipment has been repaired. After repair, the equipment will be tested to ensure that it is in proper operational condition. The client will be promptly notified in writing if defective equipment casts doubt on the validity of analytical data. The client will also be notified immediately regarding any delays due to instrument malfunctions that could impact holding times.

Laboratories will be responsible for the preparation, documentation, and implementation of the preventative maintenance program. All maintenance records will be checked on an annual

basis, according to the schedule, and will be recorded by the responsible individual. The laboratory QA/QC manager, or designee, shall be responsible for verifying compliance.

5.3.4 *Instrument Calibration*

Proper calibration of equipment and instrumentation is an integral part of the process that provides quality data. Instrumentation and equipment used to generate data must be calibrated at a frequency that ensures sufficient and consistent accuracy and reproducibility.

5.3.4.1 *Field Instrument/Equipment Calibration*

Field equipment will be calibrated prior to each sampling event according to manufacturer's recommendations and using manufacturer's standards. The equipment, calibration, and maintenance information will be documented. The frequency of calibration is dependent on the type and stability of the equipment, the methods used, the intended use of the equipment, and the recommendations of the manufacturer. Detailed information regarding the calibration and frequency of equipment calibration is provided in specific manufacturer's instruction manuals.

Equipment that fails calibration or becomes inoperable during use will be removed from service and tagged (time and date of action) to prevent inadvertent use. Such equipment will be satisfactorily recalibrated or repaired and tagged (date and time of return to service) prior to use.

5.3.4.2 *Laboratory Instrument/Equipment Calibration*

As part of their QC program, laboratories perform two types of calibrations. A periodic calibration is performed at prescribed intervals (i.e., balances, drying ovens, refrigerators, and thermometers), and operational calibrations are performed daily, at a specified frequency, or prior to analysis (i.e., initial calibrations), according to method requirements. Calibration procedures and frequency are discussed in the laboratory QA Plan. Calibrations are discussed in the laboratory standard operating procedures (SOPs) for analyses.

The laboratory QA/QC manager will be responsible for ensuring that the laboratory instrumentation is calibrated in accordance with specifications. Implementation of the calibration program shall be the responsibility of the respective laboratory group supervisors. Recognized procedures (USEPA, ASTM, or the manufacturer's instructions) shall be used when available.

Physical standards (i.e., weights or certified thermometers) shall be traceable to nationally recognized standards such as the National Institute of Standards and Technology (NIST). Chemical reference standards shall be NIST Standard Reference Materials or vendor-certified materials traceable to these standards.

The calibration requirements for each method and respective corrective actions shall be accessible, either in the laboratory SOPs or the laboratory's QA Plan for each instrument or analytical method in use. All calibrations shall be preserved on electronic media.

5.3.5 *Inspection/Acceptance Requirements for Supplies and Consumables*

Inspection and acceptance of field supplies, including laboratory-prepared sampling bottles, will be performed by the FC. All primary chemical standards and standard solutions used in this project either in the field or laboratory will be traceable to documented, reliable, commercial sources. Standards will be validated to determine their accuracy by comparison with an independent standard. Any impurities found in the standard will be documented.

6 REFERENCES

- USEPA (U.S. Environment Protection Agency), 1986. Test methods for Evaluating Solid Waste: Physical/Chemical Methods. Office of Solid Waste and Emergency Response. EPA 530/SW-846.
- USEPA, 1996. *Low-Flow (Minimal Drawdown) Ground-water Sampling Procedures*. EPA/540/S-95/504. April 1996.
- USEPA, 2008. *USEPA Contract Laboratory Program National Functional Guidelines for Superfund Organic Methods Data Review*. Office of Superfund Remediation and Technology Innovation. USEPA 540-R-08-01. June 2008.

TABLES

Table C-1
Sampling Parameters and Analytical Methods for Groundwater

Parameter	Analytical Method	Unit	Reporting Limit
Volatile Organic Compounds			
1,1,1,2-Tetrachloroethane	8260B	µg/L	0.5
1,1,1-Trichloroethane (TCA)	8260B	µg/L	0.5
1,1,2,2-Tetrachloroethane	8260B	µg/L	0.5
1,1,2-Trichloroethane	8260B	µg/L	0.5
1,1-Dichloroethane	8260B	µg/L	0.5
1,1-Dichloroethene	8260B	µg/L	0.5
1,1-Dichloropropene	8260B	µg/L	1.0
1,2,3-Trichloropropane	8260B	µg/L	1.0
1,2,3-Trichlorobenzene	8260B	µg/L	2.0
1,2,4-Trichlorobenzene	8260B	µg/L	2.0
1,2,4-Trimethylbenzene	8260B	µg/L	1.0
1,2-Dibromoethane (EDB)	8260B	µg/L	0.5
1,2-Dibro-3-chloropropane	8260B	µg/L	5.0
1,2-Dichlorobenzene	8260B	µg/L	0.5
1,2-Dichloroethane (EDC)	8260B	µg/L	0.5
1,2-Dichloropropane	8260B	µg/L	0.5
1,3-Dichlorobenzene	8260B	µg/L	0.5
1,3-Dichloropropane	8260B	µg/L	1.0
1,3,5-Trimethylbenzene	8260B	µg/L	1.0
1,4-Dichlorobenzene	8260B	µg/L	0.5
2,2-Dichloropropane	8260B	µg/L	1.0
2-Butanone (MEK)	8260B	µg/L	10.0
2-Chlorotoluene	8260B	µg/L	1.0
2-Hexanone	8260B	µg/L	10.0
4-Chlorotoluene	8260B	µg/L	1.0
4-Isopropyltoluene	8260B	µg/L	1.0
4-Methyl-2-pentanone (MIBK)	8260B	µg/L	10.0
Acetone	8260B	µg/L	20
Benzene	8260B	µg/L	0.5
Bromobenzene	8260B	µg/L	0.5
Bromochloromethane	8260B	µg/L	1.0
Bromodichloromethane	8260B	µg/L	1.0
Bromoform	8260B	µg/L	1.0
Bromomethane	8260B	µg/L	5.0
n-Butylbenzene	8260B	µg/L	1.0
sec-Butylbenzene	8260B	µg/L	1.0
tert-Butylbenzene	8260B	µg/L	1.0
Carbon Tetrachloride	8260B	µg/L	0.5
Chlorobenzene	8260B	µg/L	0.5
Chloroethane	8260B	µg/L	5.0
Chloroform	8260B	µg/L	1.0
Chloromethane	8260B	µg/L	5.0
cis-1,2-Dichloroethene	8260B	µg/L	0.5
cis-1,3-Dichloropropene	8260B	µg/L	1.0
Dibromochloromethane	8260B	µg/L	1.0
Dibromomethane	8260B	µg/L	1.0
Dichlorodifluoromethane	8260B	µg/L	1.0

Table C-1
Sampling Parameters and Analytical Methods for Groundwater

Parameter	Analytical Method	Unit	Reporting Limit
Ethylbenzene	8260B	µg/L	0.5
Hexachlorobutadiene	8260B	µg/L	5.0
Isopropylbenzene	8260B	µg/L	1.0
m,p-Xylenes	8260B	µg/L	1.0
Methyl tert-Butyl Ether	8260B	µg/L	1.0
Methylene Chloride	8260B	µg/L	5.0
n-Propylbenzene	8260B	µg/L	0.5
Naphthalene	8260B	µg/L	2.0
o-Xylene	8260B	µg/L	0.5
Styrene	8260B	µg/L	1.0
Tetrachloroethene (PCE)	8260B	µg/L	0.5
Toluene	8260B	µg/L	1.0
trans-1,2-Dichloroethene	8260B	µg/L	0.5
trans-1,3-Dichloropropene	8260B	µg/L	1.0
Trichloroethene (TCE)	8260B	µg/L	0.5
Trichlorofluoromethane	8260B	µg/L	0.5
Vinyl Acetate	8260B	µg/L	5
Vinyl Chloride	8260B	µg/L	0.5
PAHs/SVOCs (µg/L)			
Acenaphthene	8270C-SIM	µg/L	0.04
Acenaphthylene	8270C-SIM	µg/L	0.04
Anthracene	8270C-SIM	µg/L	0.04
Benzo(a)anthracene	8270C-SIM	µg/L	0.04
Benzo(a)pyrene	8270C-SIM	µg/L	0.04
Benzo(b)fluoranthene	8270C-SIM	µg/L	0.04
Benzo(k)fluoranthene	8270C-SIM	µg/L	0.04
Chrysene	8270C-SIM	µg/L	0.04
Dibenzo(a,h)anthracene	8270C-SIM	µg/L	0.04
Fluoranthene	8270C-SIM	µg/L	0.04
Fluorene	8270C-SIM	µg/L	0.04
Indeno(1,2,3-cd)pyrene	8270C-SIM	µg/L	0.04
1-Methylnaphthalene	8270C-SIM	µg/L	0.08
2-Methylnaphthalene	8270C-SIM	µg/L	0.08
Naphthalene	8270C-SIM	µg/L	0.08
Phenanthrene	8270C-SIM	µg/L	0.04
Pyrene	8270C-SIM	µg/L	0.04
Benzo(g,h,i)perylene	8270C-SIM	µg/L	0.04
Dibenzofuran	8270C-SIM	µg/L	0.04
Carbazole	8270C-SIM	µg/L	0.04
Inorganics			
Available Cyanide	OIA-1677	mg/L	0.002
Total Cyanide	USEPA 335.4	mg/L	0.005
Free Cyanide	ASTM D4282	mg/L	0.005
Metals			
Aluminum	USEPA 6020	µg/L	50
Antimony	USEPA 6020	µg/L	1
Arsenic	USEPA 6020	µg/L	2
Barium	USEPA 6020	µg/L	1

Table C-1
Sampling Parameters and Analytical Methods for Groundwater

Parameter	Analytical Method	Unit	Reporting Limit
Beryllium	USEPA 6020	µg/L	1
Cadmium	USEPA 6020	µg/L	1
Chromium	USEPA 6020	µg/L	2
Copper	USEPA 6020	µg/L	4
Iron	USEPA 6020	µg/L	100
Lead	USEPA 6020	µg/L	1
Manganese	USEPA 6020	µg/L	1
Mercury	USEPA 6020	µg/L	0.2
Nickel	USEPA 6020	µg/L	2
Selenium	USEPA 6020	µg/L	2
Silver	USEPA 6020	µg/L	1
Thallium	USEPA 6020	µg/L	1
Vanadium	USEPA 6020	µg/L	2
Zinc	USEPA 6020	µg/L	4
River Parameters			
Carbonate	SM 2320B	mg/L	20
Bicarbonate	SM 2320B	mg/L	20
Chloride	USEPA 300.0	mg/L	1
Nitrate	USEPA 300.0	mg/L	0.25
Sulfate	USEPA 300.0	mg/L	1
Calcium	USEPA 6020	µg/L	100
Iron (total and dissolved)	USEPA 6020	µg/L	100
Magnesium (total and dissolved)	USEPA 6020	µg/L	50
Potassium	USEPA 6020	µg/L	100
Sodium	USEPA 6020	µg/L	100

Notes:

µg/L= micrograms per Liter

mg/L= milligrams per Liter

PAH= polycyclic aromatic hydrocarbon

SVOC= semi-volatile organic compound

Table C-2
Container Requirements, Holding Times, and Preservation Methods for Groundwater

Parameter	Method	Sample Size	Container Size and Type	Holding Time	Sample Preservation Technique
PAHs	USEPA 8270D SIM	2 x 1 L	1-L Amber glass	7 days to extraction, 40 days to analysis	Cool/4°C
VOCs	USEPA 8260B	3 x 40 mL	40-mL glass VOA vials, Teflon-lined septum cap	14 days	Zero head space/pH < 2 with HCl
					Cool/4°C
Available Cyanide	OIA-1677	1 L	1-L Amber glass	14 days	NaOH, pH>12, Cool, 4°C
Free Cyanide	D4282	250 mL	250-mL HDPE	24 hours	NaOH, pH>12, Cool, 4°C
Total Cyanide	USEPA 335.4	500 mL	500-mL HDPE	14 days	NaOH, pH>12, Cool, 4°C
Total Metals	6010/7470	500 mL	500-mL HDPE	6 months/ 28 days Hg	HNO ₃ ; Cool/4°C

Notes:

°C = degrees Celsius

HCl = hydrochloric acid

HDPE = high density polyethylene

HNO₃ = nitric acid

L = liter

mL = milliliter

NaOH = sodium hydroxide

Table C-3
Data Quality Objectives for Groundwater

Parameter	Precision (Duplicates)	Accuracy (Spike Recoveries)	Completeness
Volatile organic compounds	+/- 30 RPD	70-130 percent R	90 percent
PAHs/ SVOC	+/- 30 RPD	50-140 percent R	90 percent
Metals	+/- 20 RPD	75-125 percent R	90 percent
Cyanide (total and available)	+/- 20 RPD	75-125 percent R	90 percent

Notes:

PAH = polycyclic aromatic hydrocarbon

R = recovery

RPD = relative percent difference

SVOC = semi-volatile organic compound

Table C-4
Laboratory Quality Control Sample Analysis Frequency for Groundwater

Analysis Type	Initial Calibration	Ongoing Calibration	Replicates	Matrix Spikes	LCS	Matrix Spike Duplicates	Method Blanks	Surrogate Spikes
Cyanide	Daily or each batch	1 per 10 samples	1 per 20 samples	1 per 20 samples	1 per 20 samples	NA	1 per 20 samples	NA
Metals	Daily	1 per 10 samples	1 per 20 samples	1 per 20 samples	1 per 20 samples	NA	1 per 20 samples	NA
SVOCs/PAHs	As needed ^a	Every 12 hours	NA	1 per 20 samples	1 per 20 samples	1 per 20 samples	1 per 20 samples	Every sample
Volatile organics	As needed ^a	Every 12 hours	NA	1 per 20 samples	1 per 20 samples	1 per 20 samples	1 per 20 samples	Every sample

Notes:

a = Initial calibrations are considered valid until the ongoing continuing calibration no longer meets method specifications. At that point, a new initial calibration is performed.

LCS = laboratory control sample

NA = not applicable

PAH = polycyclic aromatic hydrocarbon

SVOC = semi-volatile organic compound

ATTACHMENT C-1

FIELD FORMS

Daily Log



Anchor QEA, LLC
6650 SW Redwood Lane, Suite 333
Portland, OR 97224
Phone 503.670.1108 Fax 503.670.1128

PROJECT NAME: _____

DATE:

SITE ADDRESS:

PERSONNEL:

WEATHER:	WIND FROM:	N	NE	E	SE	S	SW	W	NW	LIGHT	MEDIUM	HEAVY
		SUNNY		CLOUDY		RAIN		?	TEMPERATURE:	° F _____ ° C _____		
[Circle appropriate units]												

[illegible]

Signature: _____



LOG OF
EXPLORATORY BORING

CLIENT/PROJECT NAME	BORING #
PROJECT NUMBER	DATE BEGAN
GEOLOGIST/ENGINEER	DATE COMPLETED
DRILLING CONTRACTOR	TOTAL DEPTH
DRILLING METHOD	SHEET OF
HOLE DIAMETER	

OTHER*	WELL OR PIEZOMETER DETAILS	SAMPLING DATA						DEPTH IN FEET	SOIL GROUP SYMBOL (USCS)	Field location of boring
		SAMPLING METHOD	SAMPLE NUMBER	FID / PID (ppm)	RECOVERY (feet)	BLOWS / 6 INCHES	DEPTH SAMPLED			LITHOLOGIC DESCRIPTION
								1		
								2		
								3		
								4		
								5		
								6		
								7		
								8		
								9		
								0		
								1		
								2		
								3		
								4		
								5		
								6		
								7		
								8		
								9		
								0		

Remarks:

WELL DETAILS

Project Number: _____

Client Name: _____

Project Name: _____

Location: _____

Driller: _____

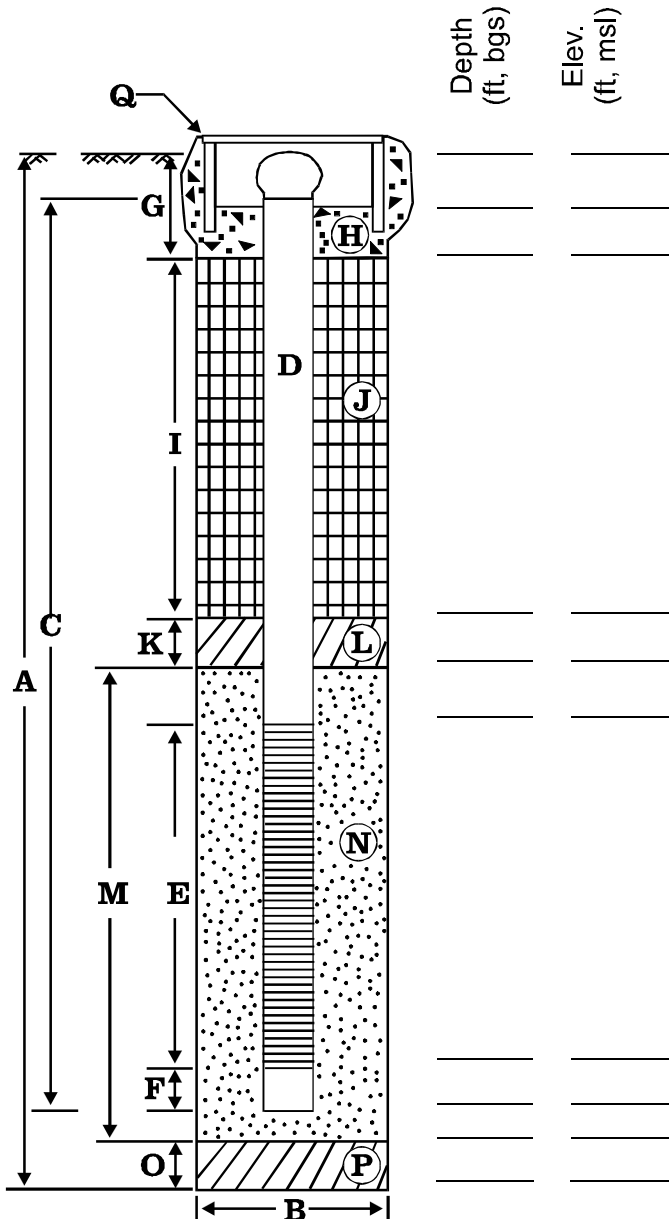
Boring/Well No.: _____

Top of Casing Elev.: _____

Ground Surface Elev.: _____

Installation Date: _____

Permit/Start Card No.: _____



EXPLORATORY BORING

A. Total depth: _____ **ft.**

B. Diameter _____ **in.**

Drilling method: _____

WELL CONSTRUCTION

C. Well casing length: _____ **ft.**

Well casing material: _____

D. Well casing diameter: _____ in.

E. Well screen length: _____ft.

Well screen type: _____

Well screen slot size: _____ in.

F. Well sump/end cap length: _____ **ft.**

G. Surface seal thickness: _____ft.

H. Surface seal material:

I. Annular seal thickness: _____ ft.

J. Annular seal material: _____

K. Filter pack seal thickness: _____ft.

L. Filter pack seal material: _____

M. Sand pack thickness: **ft.**

N. Sand pack material: _____

O. Bottom material thickness: _____ **ft.**

P. Bottom material: _____

Q. Vault box type:

Well centralizer depths: _____ ft.

NOTES:

Installed by: _____

Reviewed by: _____

Date: _____



ANCHOR
QEA

Project No.	Date:	Well:
Site Location:	Initial DTB:	Final DTB:
Name:	Initial DTW:	Final DTW:
Development Method:	Casing Volume:	
Total Water Removed:	Casing Diameter:	
Water Contained ?	Meter #:	
Estimate of specific capacity or recharge to well:		

[illegible]

FIELD SAMPLING DATA SHEET



6650 SW Redwood Lane, Suite 333
Portland, OR 97224

Office: (503) 670-1108 Fax: (503) 670-1128

PROJECT NAME:

WELL ID:

SITE ADDRESS:

BLIND ID:

DUP ID:

NA

WIND FROM:	N	NE	E	SE	S	SW	W	NW	LIGHT	MEDIUM	HEAVY
WEATHER:	SUNNY	CLOUDY	RAIN				?		TEMPERATURE:	° F	° C

HYDROLOGY/LEVEL MEASUREMENTS (Nearest 0.01 ft)

[Product Thickness]

[Water Column]

[Circle appropriate units]

[Water Column x Gal/ft]

HYDROLOGICAL MEASUREMENTS (Nearest 0.01 ft)															
Date	Time	DT-Bottom		DT-Product		DT-Water		DTP-DTW		DTB-DTW		X 1 X 3	Volume (gal)		
/ /	:		
/ /	:		
Gal/ft = (dia./2) ² x 0.163		1" =	0.041	2" =	0.163	3" =	0.367	4" =	0.653	6" =	1.469		10" =	4.080	12" =

§ METHODS: (A) Submersible Pump (B) Peristaltic Pump (C) Disposable Bailer (D) PVC/Teflon Bailer (E) Dedicated Bailer (F) Dedicated Pump (G) Other =

GROUNDWATER SAMPLING DATA (if product is detected, do NOT sample)

Sample Depth:

[√ if used]

Bottle Type	Date	Time	Method §	Amount & Volume mL	Preservative [circle]	Ice	Filter	pH	√
VOA Glass	/ /	:		3	40 ml	HCl	YES	NO	
Amber Glass	/ /	:			250, 500, 1L	(None) (HCl) (H ₂ SO ₄)	YES	NO	
White Poly	/ /	:			250, 500, 1L	None	YES	NO	NA
Yellow Poly	/ /	:			250, 500, 1L	H ₂ SO ₄	YES	NO	
Green Poly	/ /	:			250, 500, 1L	NaOH	YES	NO	
Red Total Poly	/ /	:			250, 500, 1L	HNO ₃	YES	NO	
Red Diss. Poly	/ /	:			250, 500, 1L	HNO ₃	YES	YES	
	/ /	:			250, 500, 1L		YES		

Total Bottles (include duplicate count):

Analysis Allowed per Bottle Type	BOTTLE TYPE	TYPICAL ANALYSIS ALLOWED PER BOTTLE TYPE (Circle applicable or write non-standard analysis below)
	VOA - Glass	(8021) (8260B) (BTEX) (NWTPH-Gx)
	AMBER - Glass	(PAH) (TPH-HCID) (NWTPH-Dx) (TPH-418.1) (Oil & Grease) (8081A)
	WHITE - Poly	(pH) (Conductivity) (TDS) (TSS) (BOD) (Turbidity) (Alkalinity) (HCO ₃ CO ₃) (Cl) (SO ₄) (NO ₃) (NO ₂) (F)
	YELLOW - Poly	(COD) (TOC) (Total PO ₄) (Total Keldahl Nitrogen) (NH ₃) (NO ₃ /NO ₂)
	GREEN - Poly	(Cyanide)
	RED TOTAL - Poly	(As) (Sb) (Ba) (Be) (Ca) (Cd) (Co) (Cr) (Cu) (Fe) (Pb) (Mg) (Mn) (Ni) (Ag) (Se) (Tl) (V) (Zn) (Hg) (K) (Na)
	RED DISSOLVED - Poly	(As) (Sb) (Ba) (Be) (Ca) (Cd) (Co) (Cr) (Cu) (Fe) (Pb) (Mg) (Mn) (Ni) (Ag) (Se) (Tl) (V) (Zn) (Hg) (K) (Na) (Hardness) (Silica)

WATER QUALITY DATA

Purge Start Time: :

Pump/Bailer Inlet Depth:

Meas.	Method §	Purged (gal)	pH	E Cond (μS)	°F Temp °C	Other	Diss O ₂ (mg/l)	Water Quality
4		
3		
2		
1		
0		0.00	.		.		.	

[Casing]

[Select A-G]

[Cumulative Totals]

[Circle units]

[Clarity, Color]

SAMPLER:

(PRINTED NAME)

(SIGNATURE)